# A PRACTICAL TEST OF PRIMARY CELLS

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# A THESIS

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# Preface.

The following paper will be divided into six parts as follows:-

Part I.

The Intermittent Test.

Part II.

The Open Circuit Test.

Part III.

The Temperature Test.

Part IV.

The Recuperative Test.

Part V.

Five plates showing a cross-sectional view of the cells under test.

Part VI.

Summary.

Table of Contents.

## Illustrations.



## Bibliography.


Centralblatt Accumulatoren, 8.p.22,Febr 5,1907.

" " 8.p.15,Jan.20,1907.

Electrochem. Ind. N.Y. 1.pp246-247, March 1908.

El. World and Eng. 33,pp156-157, Jan.251902.

The Voltaic Cell, by Park Bengamin,p314.

Electrician, 43,pp601-602, Aug.18,1899.

## Introduction.

From a commercial standpoint very little has been done to show how primary batteries, especially those of the dry type, stand up when subjected to various tests. Considerable attention has been directed toward the actions of primary cells using various liquids as electrolytes, and under various conditions. Experimenters have directed their attention to this class of primary batteries rather than to the so-called 'dry batteries', probably because there is much more room for investigation. Dry batteries that are used in the commercial world today are practically all of the same composition and general structure and hence afford a smaller field for investigation.

A need for data based upon the behavior of dry cells under various conditions has been felt, and the purpose of this paper is to bring out the more important points in the behavior of the batteries under these various conditions, and to give a comparative test of the different makes of cells used in the commercial world.

A set of five cells was obtained from each of eleven different manufacturers. The sets were lettered A,B,C,D,E,F,H,I,K,L, and M respectively and the sets were subdivided into A1,A2,A3, A4,A5; B1,B2, ----- ----- M5. The cells will be referred to by letter and not by name.

After the cells were properly labelled each one was carefully weighed and the weights recorded before beginning the test.

The experimental data was obtained by four different test upon each set of cells. Each test will be explained in detail with the accompanying data, curves, and drawings irrespective of any other test.

No attempt will be made to give a detailed account of the chemical action that takes place in a dry cell under such conditions as are met with in the tests.

A Short History of Primary Cells.

At the close of the 18th century there appeared no obvious connections between chemical and electrical energy, the knowledge of electricity being all together restricted to statical phenomena. The first appearance of the voltaic cell arose through a chance observation by Galvani. Late in the 18th century Volta advanced the contact theory, which assumes that when two different bodies being conductors of electricity are in contact, there is a force at the point of contact by which one of the bodies gives a part of its natural portion of electricity to the other body, which the latter takes in addition to its own natural portion. Based upon this theory, in 1799 Volta constructed a form of dry battery known as Volta's Pile, consisting of discs of zinc, wet cloth, and copper. These were placed one above the other in the order named, so that a piece of wet cloth was always encountered in passing from zinc to copper, but not from copper to zinc on continuing in the same direction. Thus a

large number of cells were constructed and connected together in series and a high electromotive force resulted. After the appearance of the Volta's Pile many new primary batteries were produced, most of them being of the so called 'wet' type. Important among this class of cells were the cells of Daniel in 1836; Grove in 1839. In 1868 the Leclanche cell appeared and from this has developed the 'dry cell'.

A large number of attempts were made before any of them proved to be successfull. Minotto used sand and copper sulphate; Wolf, Keiser, and Schmidt tried sawdust or cellulose; Desruellés filled a Leclanche cell with asbestos and spun glass; and Pollok made use of a gelatine glycerine. The first real successful dry cell was made by Gassner, and appeared in 1888, and since then it has gradually developed, until the value of this class of cells has reached a state of high development and commercial application.

The composition of the Gassner cell is practically the same as that used by most manufact-

urers today and consisted in general of oxide of zinc 1 part by weight, chloride of zinc 1 part by weight, sal-ammoniac 1 part by weight, plaster 2 parts by weight, water 2 parts by weight. The oxide of zinc loosens and makes the electrolyte more porous, thus affording easier paths for the interchange of gases, and thus diminishes the tendency toward polarization at the electrodes.

"The office of water, one of the most important constituents of a primary battery, is two fold; first, it is to dissolve and to hold in an operative condition the chemicals by which the voltaic action of the cell is excited and continued: and second, it is to dissolve and diffuse the chemical products resulting from that action. The amount of water which any cell will contain stands almost alone and nearly independent of the size and form of the electrodes as the limiting measure of the ultimate life of the battery at any work for which it is fitted. The size and form and quantity of the electrodes effect the temporary constancy of the cell,

but the question whether, in any special service for which the cell is adapted, it will continue active for one month, six months, or a year, is answered almost exclusively by the measured quantity of water which the cell is made to contain. In all batteries it is the loss of sal-ammoniac and the accumulation of zinc oxides and ammonio-compounds which determines the final failure of the battery action. And consequently the displacement of the available water of solution in any degree by absorbent solids will proportionately shorten the active life of the cell.

## Polarization.

Polarization is a condition due to the formation of a body, most commonly hydrogen, by electro-chemical decomposition upon the negative electrode, whereby a current in the opposite direction to the normal current of the cell is produced, and through which the normal current of the cell is greatly weakened.

The polarization action will not be as effective in a dry battery as in a wet battery since in a dry cell the electrolytes are made up of solid matter and the hydrogen bubbles have more difficulty in passing through the electrolyte in order to deposite themselves on the electrode. Also the amount of water from which the hydrogen is liberated is small in a dry cell in comparison to the amount in a wet cell. In the wet cell the bubbles of hydrogen find a ready path through the liquid.

Never-the-less there is some polarization action going on in a dry cell and in order to get the greatest amount of contact between the electrode and

and the electrolyte this polarization action must be reduced to as low a value as possible. Several different methods have been adopted for this purpose.

## Depolarizers.

Anything that can be put in the cell to reduce the action of polarization or to do away with it entirely is called a depolarizer. Aluminium chloride is a common depolarizer and in using it with dry cells a paste is prepared of a solution of aluminium chloride of 25 or 30 percent, and from 5 to 10 percent of magnesia; the paste conducts well and does not liquify when hot. The aluminium chloride does not attack the zinc, the negative electrode, which may also be made of aluminium. Another good depolarizer can be made by mixing a concentrated solution of ferric chloride with graphite and manganese dioxide, and compress the mixture in bags of linen. The electrolyte consists of chloride of zinc, ammonium, and magnesium, and is brought to the consistency of

dough by being mixed with gum arabic, containing arabic and metarabic acids, together with finely ground bones. The depolarizer bag is forced within the zinc cylinder into this dough, which latter prevents diffusion of ferric chloride to the zinc.

Each manufacturer of dry cells uses his own method for the prevention of polarization, and the two methods cited above are by no means the ones in general practice. But it was thought advisable to give a few of the methods of doing away with polarization in order to give the reader some idea of the difficulties met with in the manufacture of a first class primary cell of the dry type.

## Part I.

### The Intermittent Test.

The object of this test is to show the behavior of a dry cell when operating under conditions approaching the practical as near as can be assumed.

Figure I.

A scheme for connecting up the apparatus used in the intermittent test. An explanation of this scheme is to be found in the first part of the intermittent test.

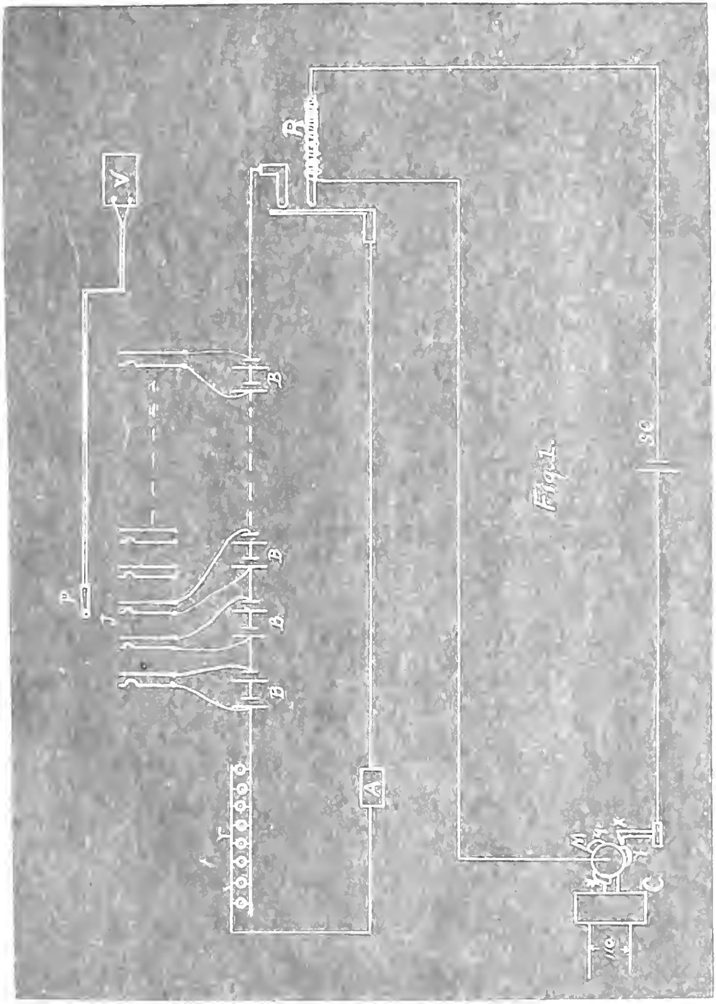



Fig. 1.

## The Intermittent Test.

The intermittent test is no boubt the most practical test that a dry cell can be submitted to; because it is for this class of work that the dry cell is manufactured. It was to this test that the greater amount of time was given. The apparatus, other than the cells necessary for obtaining the experimental data for this part consisted of the following;

(1) Clock mechanism with intermittent contact maker attached.

(2) 0-5 Direct current direct reading ammeter.

(3) 0-3 " " " " voltm'r.

(4) Telephone jack with plug.

(5) Incandescent lamps in parallel for adjustment of resistance.

(6) Relay for closing battery circuit.

(7) Storage cell for exciting relay.

The apparatus was connected according to the scheme shown in Fig 1. Two cells of each of the different makes were chosen and connected in series

through a resistance r, an ammeter A, and relay R. The resistance r consisted of several thirty-two candle-power incandescent lamps connected in parallel so the resistance could be adjusted to any desired value from about 12 ohms to 220 ohms. The greater the number of lamps the less the resistance. Across each group of cells was connected a telephone jack J. The plug P was connected to the voltmeter V. By inserting the plug in the jack, the voltage across two cells comprising a group can be read on the voltmeter.

The closk mechanism was operated on a 110-volt lighting circuit. In place of the minute hand that is found on an ordinary clock was a brass disc with three contact arms y,y,and y. The disc was connected to one side of the magnetizing coil of the relay R, while to the other side of the coil was connected a storage cell SC to the contact point x, secured to the base of the clock. The arms of the contact maker are of sufficient size to close the

circuit for a period of two minutes out of every twenty minutes. When the point x comes in contact with y, the circuit is closed through the storage cell, which, in turn operates the relay closing the battery circuit. Thus the cells discharge current, the value of which depends on the resistance r. The battery circuit will be closed as long as x is in contact with y, in other words, the apparatus is so timed that the cells will discharge for a period of two minutes out of each twenty minutes, or one tenth of the time.

At the beginning of the test the value of the resistance r was adjusted to such a value that the batteries gave out current to the value of 1.58 amperes. This value of current of course decreased as the cells weakened.

During the test the values of the current and the voltage were read once every twenty four hours. The voltage was taken across two similiar cells in series, and assuming the voltage of the two cells to be the same, an assumption causing very little error, if any, since the cells are of the same

make, the voltage as read by the voltmeter was divided by two to get the voltage per cell. Knowing the voltage and the current per cell, the watts were calculated according to the formula

$$W = E \cdot I.$$

Then knowing the duration of the test and the fraction of this time that the batteries were short circuited, (In this case it was one tenth of the time) the watt-hours output from each cell was found by using the formula

$$W = E \cdot I \cdot t,$$

where E is the voltage per cell, I is the current per cell, and t is the time, in hours, that the cell was on short circuit. Knowing now the total watt-hours output, the watt-hours per cubic inch can be found by dividing the total watt-hours by the volume of the electrolyte in cubic inches. The volume of the electrolyte being the volume of the cell less the volume of the carbon.

The test was carried on for twenty four days, during which time the current dropped from as high a value as 1.58 amperes to as low a value as .275 amperes, and the voltage dropped from as high a value as 1.52 volts to as low a value as .3625 volts, depending upon the make of cell. However in most of the cells the minimum value of voltage reached a value of about .9 volts. The test was continued no longer because the internal resistance of the cell had risen to such a high value that below .8 or .9 of a volt the cell is of little practical value in the commercial field. The difference in internal resistance before and after the test reached a value in one case of 6.32 ohms, while in another case it was only 1.59 ohms.

Data on Intermittent Test.

Battery "A"

| Days | E | I | Hours on short circuit | Watt-hours | Watt-hours / cu in. |
|---|---|---|---|---|---|
| 1 | 1.5075 | 1.5675 | 2.4 | 5.67 | .2500 |
| 2 | 1.4450 | 1.3250 | 2.4 | 4.60 | .2020 |
| 3 | 1.2800 | 1.2250 | 2.4 | 3.77 | .1660 |
| 4 | 1.2700 | 1.0000 | 6.0 | 7.62 | .3360 |
| 5 | 1.2525 | .9500 | 2.4 | 2.85 | .1280 |
| 6 | 1.2270 | .8750 | 5.1 | 2.72 | .1420 |
| 7 | 1.2175 | .8750 | 2.4 | 5.43 | .2440 |
| 8 | 1.1900 | .7750 | 9.6 | 8.48 | .3820 |
| 9 | 1.1700 | .7250 | 2.4 | 2.03 | .0915 |
| 10 | 1.1600 | .6750 | 2.4 | 1.88 | .0847 |
| 11 | 1.1125 | .5800 | 2.4 | 1.54 | .0695 |
| 12 | 1.1000 | .5300 | 2.4 | 1.36 | .0631 |
| 13 | 1.0750 | .5300 | 2.4 | 1.40 | .0613 |
| 14 | 1.0500 | .4750 | 2.4 | 1.19 | .0586 |
| 15 | 1.0500 | .4250 | 2.4 | 1.07 | .0482 |
| 16 | 1.0250 | .3750 | 2.4 | .92 | .0414 |
| 17 | .9750 | .3500 | 2.4 | .82 | .0369 |
| 18 | .9750 | .3500 | 2.4 | .82 | .0369 |
| 19 | .9625 | .3260 | 2.4 | .75 | .0338 |
| 20 | .9500 | .3250 | 2.4 | .74 | .0333 |
| 21 | .9500 | .3250 | 2.4 | .74 | .0333 |
| 22 | .9250 | .3250 | 2.4 | .72 | .0324 |
| 23 | .9000 | .3100 | 2.4 | .67 | .0302 |
| 24 | .8500 | .3000 | 2.4 | .66 | .0299 |
| | | | Total- - - - | 58.45 | |

Average watt-hours per cubic inch = 2.63

Internal Resistance before test = 0.243

" " after " = 5.000

Data on Intermittent Test.

Battery "B"

| Days | E | I | Hours on short circuit | Watt-hours | Watt-hours / cu in. |
|---|---|---|---|---|---|
| 1 | 1.4350 | 1.5674 | 2.4 | 5.40 | .2580 |
| 2 | 1.2850 | 1.3250 | 2.4 | 4.09 | .1955 |
| 3 | 1.2225 | 1.2250 | 2.4 | 3.59 | .1715 |
| 4 | 1.1700 | 1.0000 | 6.0 | 7.02 | .3360 |
| 5 | 1.1625 | .9500 | 2.4 | 2.65 | .1267 |
| 6 | 1.1425 | .9250 | 2.4 | 2.53 | .1210 |
| 7 | 1.1200 | .8750 | 5.1 | 5.00 | .2390 |
| 8 | 1.0625 | .7750 | 9.6 | 7.90 | .3770 |
| 9 | 1.0575 | .7250 | 2.4 | 1.84 | .0880 |
| 10 | 1.0450 | .6750 | 2.4 | 1.69 | .0810 |
| 11 | .9875 | .5800 | 2.4 | 1.37 | .0655 |
| 12 | .9500 | .5300 | 2.4 | 1.21 | .0579 |
| 13 | .9250 | .5300 | 2.4 | 1.18 | .0565 |
| 14 | .9200 | .4750 | 2.4 | 1.05 | .0502 |
| 15 | .9000 | .4250 | 2.4 | .92 | .0440 |
| 16 | .8875 | .3750 | 2.4 | .80 | .0381 |
| 17 | .8625 | .3500 | 2.4 | .72 | .0344 |
| 18 | .8375 | .3500 | 2.4 | .70 | .0335 |
| 19 | .8375 | .3250 | 2.4 | .65 | .0311 |
| 20 | .8325 | .3250 | 2.4 | .65 | .0311 |
| 21 | .8250 | .3250 | 2.4 | .644 | .0308 |
| 22 | .8000 | .3250 | 2.4 | .625 | .0299 |
| 23 | .7750 | .3100 | 2.4 | .578 | .0276 |
| 24 | .7250 | .3000 | 2.4 | .523 | .0274 |
| | | | Total - - - | 53.33 | |

Average watt-hours per cubic inch 2.55

Internal resistance before test .307

" " after " 2.517

Data on Intermittent Test.

Battery "D"

| Days | E | I | Hours on short circuit | Watt-hours | Watt-hours / cu in. |
|---|---|---|---|---|---|
| 1 | 1.4300 | 1.5675 | 2.4 | 5.38 | .2670 |
| 2 | 1.2350 | 1.3250 | 2.4 | 3.93 | .1785 |
| 3 | 1.1825 | 1.2250 | 2.4 | 3.48 | .1580 |
| 4 | 1.1050 | 1.0000 | 6.0 | 6.63 | .3100 |
| 5 | 1.1000 | .9500 | 2.4 | 2.50 | .1135 |
| 6 | 1.0700 | .9250 | 2.4 | 2.37 | .1075 |
| 7 | 1.0375 | .8750 | 5.1 | 4.62 | .2100 |
| 8 | 1.0250 | .7750 | 9.6 | 7.62 | .2460 |
| 9 | 1.0250 | .7250 | 2.4 | 1.79 | .0814 |
| 10 | 1.0250 | .6750 | 2.4 | 1.66 | .0748 |
| 11 | 1.0200 | .5800 | 2.4 | 1.42 | .0646 |
| 12 | 1.0100 | .5300 | 2.4 | 1.28 | .0582 |
| 13 | 1.0075 | .5300 | 2.4 | 1.28 | .0582 |
| 14 | 1.0000 | .4750 | 2.4 | 1.14 | .0518 |
| 15 | .9875 | .4250 | 2.4 | 1.01 | .0460 |
| 16 | .9750 | .3750 | 2.4 | .88 | .0400 |
| 17 | .9700 | .3500 | 2.4 | .82 | .0372 |
| 18 | .9675 | .3500 | 2.4 | .81 | .0368 |
| 19 | .9675 | .3250 | 2.4 | .75 | .0340 |
| 20 | .9650 | .3250 | 2.4 | .74 | .0336 |
| 21 | .9650 | .3250 | 2.4 | .74 | .0336 |
| 22 | .9575 | .3250 | 2.4 | .72 | .0327 |
| 23 | .9500 | .3100 | 2.4 | .70 | .03180 |
| 24 | .9250 | .3000 | 2.4 | .67 | .0304 |
| | | | Total- | 52.94 | |

Average watt-hours per cubic inch 2.400

Internal resistance before test .293

" " after " 2.687

Data on Intermittent Test.

Battery "E"

| Days | E | I | Hours on short circuit | Watt-hours | Watt-hours / cu in. |
|---|---|---|---|---|---|
| 1 | 1.4500 | 1.5675 | 2.4 | 5.45 | .2600 |
| 2 | 1.3250 | 1.3250 | 2.4 | 4.20 | .2005 |
| 3 | 1.2675 | 1.2250 | 2.4 | 3.73 | .1785 |
| 4 | 1.2425 | 1.0000 | 6.0 | 7.45 | .3560 |
| 5 | 1.2210 | .9500 | 2.4 | 2.78 | .1330 |
| 6 | 1.2175 | .9250 | 2.4 | 2.70 | .1290 |
| 7 | 1.1825 | .8750 | 5.1 | 5.28 | .2525 |
| 8 | 1.1775 | .7750 | 9.6 | 8.75 | .4180 |
| 9 | 1.1500 | .7250 | 2.4 | 2.00 | .0955 |
| 10 | 1.1500 | .6750 | 2.4 | 1.86 | .0890 |
| 11 | 1.1450 | .6800 | 2.4 | 1.60 | .0766 |
| 12 | 1.1250 | .5300 | 2.4 | 1.43 | .0685 |
| 13 | 1.0700 | .5300 | 2.4 | 1.36 | .0651 |
| 14 | 1.0250 | .4750 | 2.4 | 1.17 | .0560 |
| 15 | 1.0125 | .4250 | 2.4 | 1.03 | .0493 |
| 16 | .9875 | .3750 | 2.4 | .89 | .0426 |
| 17 | .9000 | .3500 | 2.4 | .76 | .0364 |
| 18 | .8750 | .3500 | 2.4 | .74 | .0354 |
| 19 | .8750 | .3250 | 2.4 | .69 | .0330 |
| 20 | .8500 | .3250 | 2.4 | .66 | .0315 |
| 21 | .8375 | .2250 | 2.4 | .65 | .0311 |
| 22 | .8250 | .3250 | 2.4 | .64 | .0306 |
| 23 | .7750 | .3100 | 2.4 | .58 | .0277 |
| 24 | .7750 | .3000 | 2.4 | .57 | .0271 |
| | | | Total - - | -56.97 | |

Average watt-hours per cubic inch 2.720

Internal resistance before test .189

" " after " 1.591

Data on Intermittent Test.

Battery "F"

| Days | E | I | Hours on short circuit | Watt-hours | Watt-hours / cu in. |
|---|---|---|---|---|---|
| 1 | 1.5200 | 1.5675 | 2.4 | 5.70 | .2700 |
| 2 | 1.4250 | 1.3250 | 2.4 | 4.55 | .2160 |
| 3 | 1.2650 | 1.2250 | 2.4 | 3.72 | .1760 |
| 4 | 1.2375 | 1.0000 | 6.0 | 7.42 | .3520 |
| 5 | 1.1865 | .9500 | 2.4 | 2.70 | .1280 |
| 6 | 1.1825 | .9250 | 2.4 | 2.62 | .1240 |
| 7 | 1.1250 | .8750 | 5.1 | 5.02 | .2480 |
| 8 | 1.1100 | .7750 | 9.6 | 8.25 | .3730 |
| 9 | 1.1000 | .7250 | 2.4 | 1.91 | .0908 |
| 10 | 1.1000 | .6750 | 2.4 | 1.78 | .0845 |
| 11 | 1.0825 | .5800 | 2.4 | 1.51 | .0716 |
| 12 | 1.0825 | .5300 | 2.4 | 1.38 | .0650 |
| 13 | 1.0675 | .5300 | 2.4 | 1.36 | .0645 |
| 14 | 1.0625 | .4750 | 2.4 | 1.21 | .0573 |
| 15 | 1.0625 | .4250 | 2.4 | 1.08 | .0512 |
| 16 | 1.0500 | .3750 | 2.4 | .95 | .0460 |
| 17 | 1.0500 | .3500 | 2.4 | .88 | .0416 |
| 18 | 1.0313 | .3500 | 2.4 | .87 | .0412 |
| 19 | 1.0250 | .3250 | 2.4 | .80 | .0379 |
| 20 | 1.0250 | .3250 | 2.4 | .80 | .0379 |
| 21 | 1.0250 | .3250 | 2.4 | .80 | .0379 |
| 22 | 1.0250 | .3250 | 2.4 | .80 | .0379 |
| 23 | .9850 | .3100 | 2.4 | .73 | .0346 |
| 24 | .9700 | .3000 | 2.4 | .70 | .0332 |
| | | | Total- - | 57.54 | |

Average watt-hours per cubic inch 2.740

Internal resistance before test .166

" " after " 3.042

Data on Intermittent Test.

Battery "H"

| Days | E | I | Hours on short circuit | Watt-hours | Watt-hours / cu in. |
|---|---|---|---|---|---|
| 1 | 1.4850 | 1.5675 | 2.4 | 5.60 | .2745 |
| 2 | 1.4250 | 1.3250 | 2.4 | 4.53 | .2220 |
| 3 | 1.2600 | 1.2250 | 2.4 | 3.70 | .1815 |
| 4 | 1.2275 | 1.0000 | 6.0 | 7.38 | .3620 |
| 5 | 1.2150 | .9500 | 2.4 | 2.77 | .1360 |
| 6 | 1.2063 | .9250 | 2.4 | 2.68 | .1315 |
| 7 | 1.1400 | .8750 | 5.1 | 5.10 | .2500 |
| 8 | 1.1075 | .7750 | 9.6 | 8.25 | .4040 |
| 9 | 1.1000 | .7250 | 2.4 | 1.92 | .0943 |
| 10 | 1.0725 | .6750 | 2.4 | 1.74 | .0854 |
| 11 | 1.0250 | .5800 | 2.4 | 1.43 | .0695 |
| 12 | .9825 | .5300 | 2.4 | 1.25 | .0613 |
| 13 | .9400 | .5300 | 2.4 | 1.20 | .0590 |
| 14 | .9175 | .4750 | 2.4 | 1.05 | .0515 |
| 15 | .8500 | .4250 | 2.4 | .87 | .0476 |
| 16 | .4750 | .3750 | 2.4 | .43 | .0211 |
| 17 | .4250 | .3500 | 1.8 | .27 | .0133 |
| | | | Total- - | -50.17 | |

Average watt- hours per cubic inch 2.46

Internal resistance before test .274

" " after " 3.510

Data on Intermittent Test.

Battery "I"

| Days | E | I | Hours on short circuit | Watt-hours | Watt-hours / cu in. |
|---|---|---|---|---|---|
| 1 | 1.4425 | 1.5675 | 2.4 | 5.42 | .2660 |
| 2 | 1.1925 | 1.3250 | 2.4 | 3.97 | .1950 |
| 3 | 1.2475 | 1.2250 | 2.4 | 3.52 | .1730 |
| 4 | 1.1125 | 1.0000 | 6.0 | 6.67 | .3270 |
| 5 | 1.0650 | .9500 | 2.4 | 2.42 | .1188 |
| 6 | 1.0750 | .9250 | 2.4 | 2.39 | .1172 |
| 7 | 1.0375 | .8750 | 5.1 | 4.64 | .2275 |
| 8 | 1.0325 | .7250 | 9.6 | 7.70 | .3780 |
| 9 | 1.0325 | .7250 | 2.4 | 1.80 | .0885 |
| 10 | 1.0250 | .6750 | 2.4 | 1.66 | .0815 |
| 11 | 1.0125 | .5800 | 2.4 | 1.41 | .0695 |
| 12 | 1.0075 | .5300 | 2.4 | 1.28 | .0629 |
| 13 | .9925 | .5300 | 2.4 | 1.26 | .0618 |
| 14 | .9875 | .4750 | 2.4 | 1.12 | .0550 |
| 15 | .9860 | .4250 | 2.4 | 1.01 | .0495 |
| 16 | .9825 | .3750 | 2.4 | .89 | .0437 |
| 17 | .9800 | .3500 | 2.4 | .83 | .0407 |
| 18 | .9800 | .3500 | 2.4 | .82 | .0402 |
| 19 | .9775 | .3250 | 2.4 | .76 | .0373 |
| 20 | .9750 | .3250 | 2.4 | .76 | .0373 |
| 21 | .9750 | .3250 | 2.4 | .76 | .0373 |
| 22 | .9725 | .3250 | 2.4 | .75 | .0368 |
| 23 | .9500 | .3100 | 2.4 | .71 | .0348 |
| 24 | .8250 | .3000 | 2.4 | .60 | .0294 |
| | | | TOtal - - | -53.15 | |

Average watt-hours per cubic inch 2.610

Internal resistance before test .248

" " after " 4.310

Data on Intermittent Test.

Battery "K"

| Days | E | I | Hours on short circuit | Watt-hours | Watt-hours / cu in. |
|---|---|---|---|---|---|
| 1 | 1.4850 | 1.5675 | 2.4 | 5.58 | .2790 |
| 2 | 1.3575 | 1.3250 | 2.4 | 4.31 | .2155 |
| 3 | 1.2925 | 1.2250 | 2.4 | 3.80 | .1900 |
| 4 | 1.2875 | 1.0000 | 6.0 | 7.70 | .1350 |
| 5 | 1.2220 | .9500 | 2.4 | 2.78 | .1390 |
| 6 | 1.2500 | .9250 | 2.4 | 2.78 | .1390 |
| 7 | 1.2025 | .8750 | 5.1 | 5.40 | .2700 |
| 8 | 1.2025 | .7750 | 9.6 | 8.95 | .4475 |
| 9 | 1.1750 | .7250 | 2.4 | 2.02 | .1010 |
| 10 | 1.1625 | .6750 | 2.4 | 1.89 | .0945 |
| 11 | 1.1125 | .5800 | 2.4 | 1.55 | .0775 |
| 12 | 1.0575 | .5300 | 2.4 | 1.34 | .0670 |
| 13 | 1.0175 | .5300 | 2.4 | 1.30 | .0650 |
| 14 | .9550 | .4750 | 2.4 | 1.09 | .0545 |
| 15 | .9250 | .4250 | 2.4 | .94 | .0470 |
| 16 | .9125 | .2750 | 2.4 | .82 | .0410 |
| 17 | .8925 | .3500 | 2.4 | .75 | .0375 |
| 18 | .7250 | .3500 | 2.4 | .61 | .0305 |
| 19 | .7125 | .3250 | 2.4 | .56 | .0288 |
| 20 | .6750 | .3250 | 2.4 | .53 | .0265 |
| 21 | .6750 | .3250 | 2.4 | .53 | .0265 |
| 22 | .6625 | .3250 | 2.4 | .51 | .0255 |
| 23 | .5875 | .3100 | 2.4 | .44 | .0220 |
| 24 | .3625 | .3100 | 2.4 | .27 | .0135 |
| | | | Total - - | 56.45 | |

Average watt-hours per cubic inch 2.823

Internal resistance before test .238

" " after " 4.000

Data on Intermittent Test.

Battery "L"

| Days | E | I | Hours on short circuit | Watt-hours | Watt-hours / cu in. |
|---|---|---|---|---|---|
| 1 | 1.4275 | 1.5675 | 2.4 | 5.35 | .2500 |
| 2 | 1.2000 | 1.3250 | 2.4 | 1.59 | .0745 |
| 3 | 1.0788 | 1.2250 | 2.4 | 3.41 | .1595 |
| 4 | 1.0688 | 1.0000 | 6.0 | 6.41 | .3000 |
| 5 | .9925 | .9500 | 2.4 | 2.26 | .1060 |
| 6 | .9675 | .9250 | 2.4 | 2.19 | .1025 |
| 7 | .9625 | .8750 | 5.1 | 4.28 | .2000 |
| 8 | .9500 | .7750 | 9.6 | 7.06 | .3300 |
| 9 | .9375 | .7250 | 2.4 | 1.63 | .0763 |
| 10 | .9325 | .6750 | 2.4 | 1.51 | .0706 |
| 11 | .9300 | .5800 | 2.4 | 1.29 | .0603 |
| 12 | .9125 | .5300 | 2.4 | 1.16 | .0542 |
| 13 | .9125 | .5300 | 2.4 | 1.16 | .0542 |
| 14 | .8938 | .4750 | 2.4 | 1.02 | .0476 |
| 15 | .8875 | .4250 | 2.4 | .90 | .0420 |
| 16 | .8750 | .3750 | 2.4 | .79 | .0369 |
| 17 | .8625 | .3500 | 2.4 | .73 | .0341 |
| 18 | .8625 | .3500 | 2.4 | .73 | .0341 |
| 19 | .8500 | .3250 | 2.4 | .66 | .0308 |
| 20 | .8500 | .3250 | 2.4 | .66 | .0308 |
| 21 | .8425 | .3250 | 2.4 | .65 | .0304 |
| 22 | .8333 | .3250 | 2.4 | .64 | .0299 |
| 23 | .7825 | .3100 | 2.4 | .60 | .0280 |
| | | | Total- | - 46.68 | |

Average watt-hours per cubic inch 2.180

Internal resistance before test .430

" " after " 6.650

Data on Intermittent Test.

Battery "M"

| Days | E | I | Hours on short circuit | Watt-hours | Watt-hours / cu in. |
|---|---|---|---|---|---|
| 1 | 1.4800 | 1.5675 | 2.4 | 5.57 | .2785 |
| 2 | 1.4425 | 1.3250 | 2.4 | 4.60 | .2300 |
| 3 | 1.2850 | 1.2250 | 2.4 | 3.78 | .1890 |
| 4 | 1.2400 | 1.0000 | 6.0 | 7.45 | .3725 |
| 5 | 1.2300 | .9500 | 2.4 | 2.80 | .1400 |
| 6 | 1.1975 | .9250 | 2.4 | 2.66 | .1330 |
| 7 | 1.1375 | .8750 | 5.1 | 5.07 | .2525 |
| 8 | 1.1188 | .7750 | 9.6 | 8.80 | .4400 |
| 9 | 1.0825 | .7250 | 2.4 | 1.89 | .0945 |
| 10 | 1.0575 | .6750 | 2.4 | 1.71 | .0855 |
| 11 | 1.0150 | .5800 | 2.4 | 1.41 | .0705 |
| 12 | 1.0125 | .5300 | 2.4 | 1.29 | .0645 |
| 13 | .9250 | .5300 | 2.4 | 1.18 | .0590 |
| 14 | .8750 | .4750 | 2.4 | 1.00 | .0500 |
| 15 | .8500 | .4250 | 2.4 | .87 | .0435 |
| 16 | .7500 | .3750 | 2.4 | .68 | .0340 |
| 17 | .4500 | .3500 | 2.0 | .04 | .0200 |
| | | | Total - - - | 50.80 | |

Average watt-hours per cubic inch 2.541

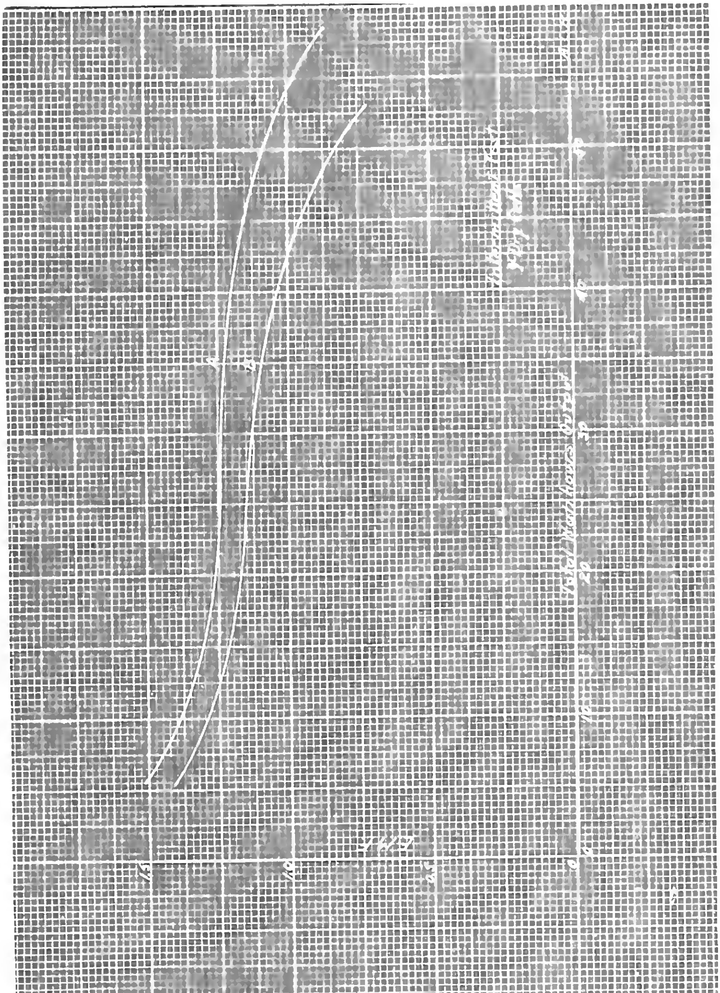
Internal resistance before test .160

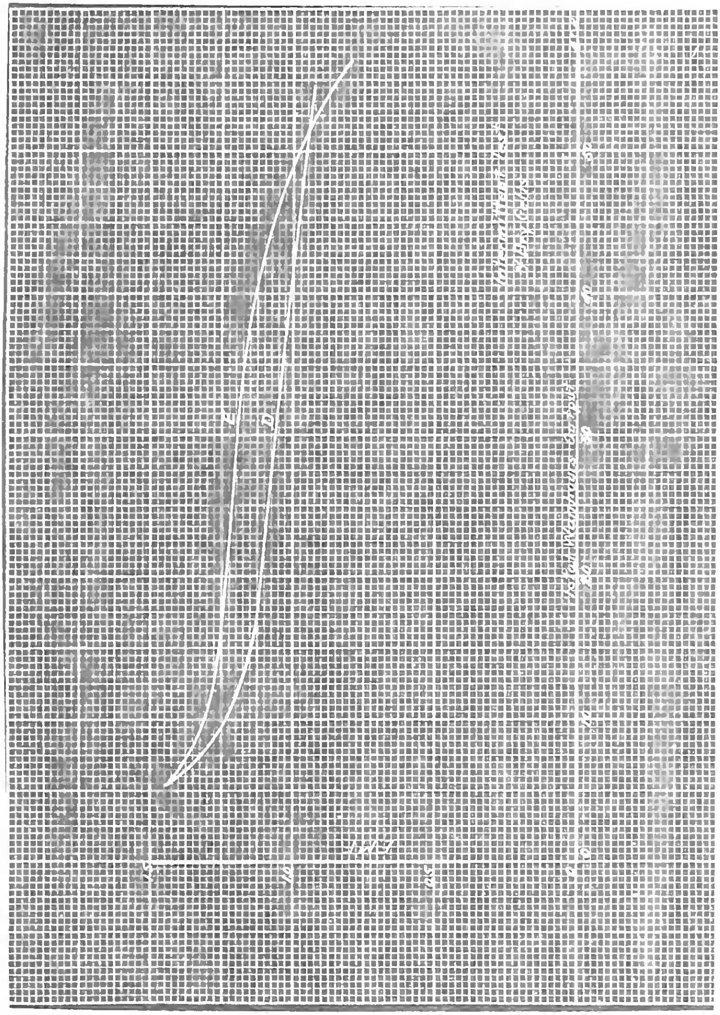
" " after " -----

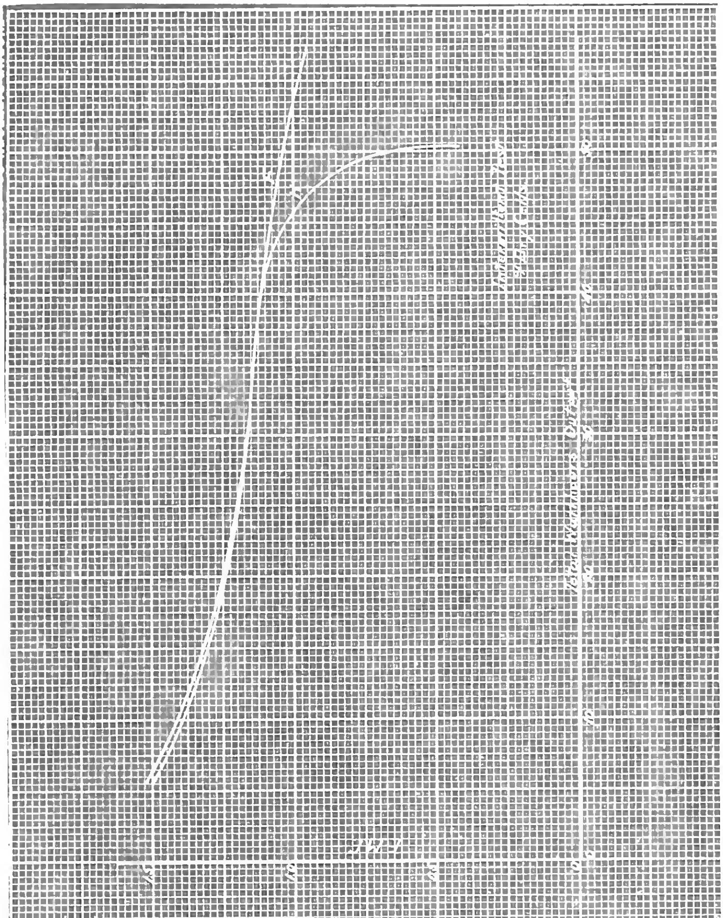
Curves.

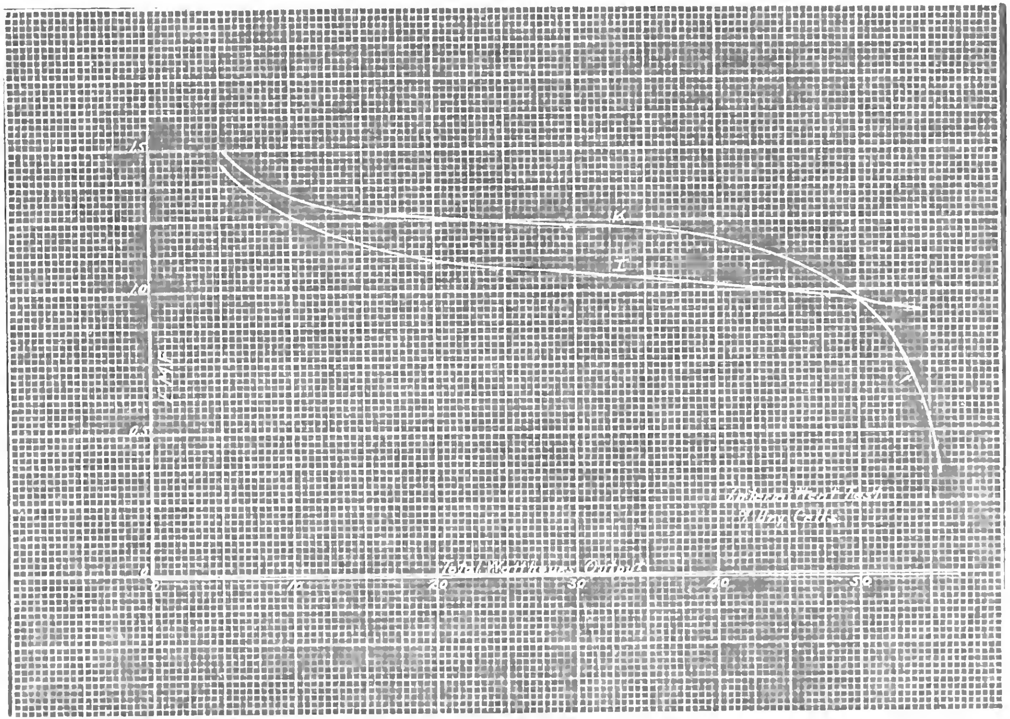
Intermittent Test.

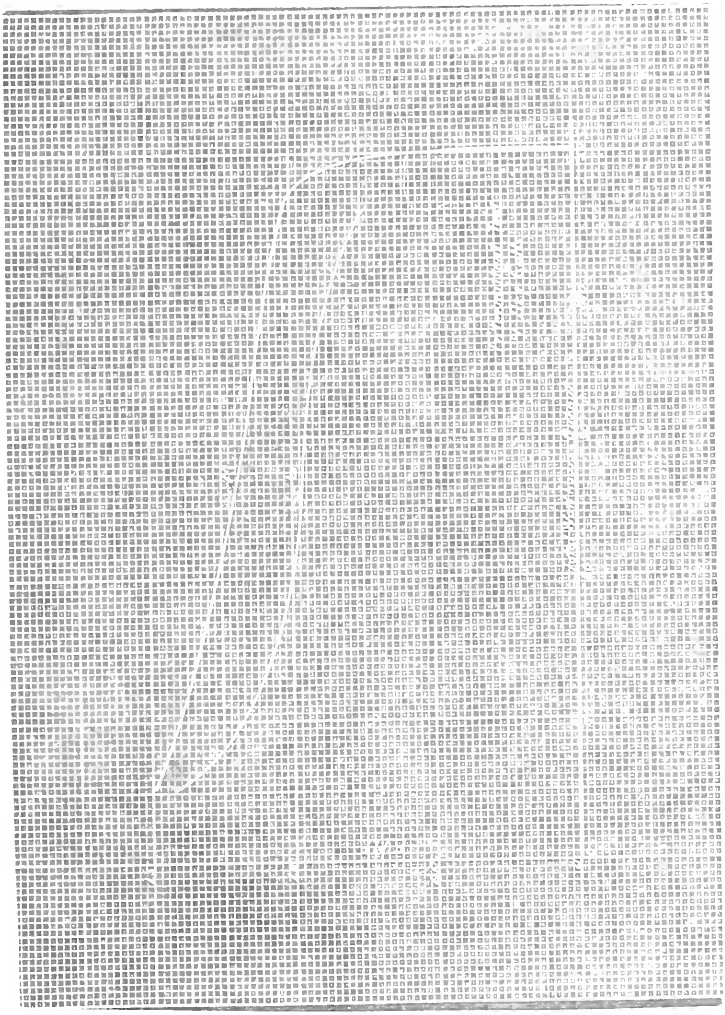
Curves showing the relation between the watt-hours output and the open-circuit electromotive force of the cells under test.








1.5
1.0
0.5
0
E.M.F.
0
10
20
30
40
50
Total Watt hours Output
K
I
Alloy Cells



By referring to the curves it will be seen that the value of the voltage of practically all of the cells drops with considerable rapidity for the first few watt-hours output. Between 20 watt-hours and 35 watt-hours discharge the value of voltage for cells A and B drops off very slowly, after which time it drops off quite rapidly again.

Between the values 15 watt-hours and 35 watt-hours the voltage of cell E drops slowly, after which it drops off more rapidly again.

Between the values 20 watt-hours and 55 watt-hours the voltage of D drops off quite gradually.

Between the values 30 watt-hours and 40 watt-hours cell F drops very slowly, more rapidly from there on.

Between 30 watt-hours and 40 watt-hours the voltage of cell H drops ver slowly, while from 40 watt-hours to 50 watt-hours it drops very rapidly, and at 50 assumes practically a vertical line.

Between 15 watt-hours and 35 watt-hours the voltage of K drops off very slowly; from 35 watt-hours to 50 watt-hours it drops very rapidly.

Between 20 watt-hours and 50 watt-hours the voltage of I drops off very gradually.

Between 20 watt-hours and 30 watt-hours the voltage of L drops off slowly, more rapidly from this point on.

Between 5 watt-hours and 47 watt-hours the voltage of M drops off gradually, while after 47 watt-hours the voltage drops very rapidly, reaching a zero value at 50 watt-hours.

## Part II.

### The Open Circuit Test.

The purpose of this test is to show the behavior of dry cells when standing idle.

## The Open Circuit Test.

When dry cells are allowed to stand idle there is a slight depreciation in their open-circut electromotive force. This loss of potential is due mostly to polarization in the cell itself, although it is very probable that there are other causes due to the chemical action of the cell. But since the chemical action taking place in a dry cell was not ascertained, it will be assumed that the loss of voltage was due to the polarization.

The test consisted only of connecting a voltmeter across one of the cells of each make and reading the voltage of the cell as given by the voltmeter. These readings were taken once every twenty four hours for forty eight days. During that length of time the voltage had dropped but a very slight degree, ranging from 0 volts at the lowest to .085 of a volt at the highest. The cells having the greatest amount of polarization deteriorate the fastest.

Assuming that the voltage drops more rapidly as the length of time increases, it would be safe to say that in three months the voltage of the cell that gave .085 of a volt drop for forty eight days would have its open circuit electromotive force decreased an amount equal to .2 of a volt. Now when we stop to consider that when the value of voltage of a dry cell reaches a value as low as .8 of a volt, the cell is practically useless, with regards to efficiency.

Therefore to get the highest efficiency from a dry cell it should be put into use as soon as possible after it has gone through the necessary processes of manufacture.

Data on the Open Circuit Test.

Battery "A"

Taken each day for 48 days.

| Volts | Volts | Volts |
|---|---|---|
| 1.530 | 1.523 | 1.517 |
| 1.530 | 1.523 | 1.517 |
| 1.530 | 1.523 | 1.515 |
| 1.530 | 1.523 | 1.515 |
| 1.530 | 1.523 | 1.510 |
| 1.527 | 1.520 | 1.510 |
| 1.527 | 1.520 | 1.510 |
| 1.527 | 1.520 | 1.510 |
| 1.525 | 1.520 | 1.510 |
| 1.525 | 1.520 | 1.510 |
| 1.525 | 1.520 | 1.500 |
| 1.525 | 1.520 | 1.500 |
| 1.525 | 1.520 | 1.500 |
| 1.525 | 1.520 | 1.500 |
| 1.525 | 1.520 | 1.500 |
| 1.525 | 1.520 | 1.500 |

Data on the Open Circuit Test.

Battery "B"

Taken each day for 48 days.

| Volts | Volts | Volts |
|---|---|---|
| 1.460 | 1.450 | 1.430 |
| 1.460 | 1.450 | 1.430 |
| 1.460 | 1.450 | 1.435 |
| 1.460 | 1.450 | 1.435 |
| 1.460 | 1.450 | 1.430 |
| 1.460 | 1.450 | 1.430 |
| 1.460 | 1.450 | 1.430 |
| 1.460 | 1.450 | 1.430 |
| 1.460 | 1.450 | 1.425 |
| 1.460 | 1.450 | 1.425 |
| 1.455 | 1.445 | 1.425 |
| 1.455 | 1.445 | 1.420 |
| 1.455 | 1.445 | 1.420 |
| 1.455 | 1.445 | 1.420 |
| 1.450 | 1.445 | 1.420 |
| 1.450 | 1.445 | 1.420 |

Data on the Open Circuit Test.

Battery "D"

Taken each day for 48 days.

| Volts | Volts | Volts |
|---|---|---|
| 1.430 | 1.425 | 1.415 |
| 1.430 | 1.425 | 1.415 |
| 1.430 | 1.425 | 1.415 |
| 1.430 | 1.425 | 1.415 |
| 1.430 | 1.425 | 1.415 |
| 1.430 | 1.425 | 1.415 |
| 1.430 | 1.420 | 1.410 |
| 1.430 | 1.420 | 1.410 |
| 1.430 | 1.420 | 1.410 |
| 1.430 | 1.420 | 1.410 |
| 1.430 | 1.420 | 1.400 |
| 1.430 | 1.415 | 1.400 |
| 1.425 | 1.415 | 1.400 |
| 1.425 | 1.415 | 1.400 |
| 1.425 | 1.415 | 1.400 |
| 1.425 | 1.415 | 1.400 |

Data on the Open Circuit Test.

Battery "E"

Taken each day for 48 days.

| Volts | Volts | Volts |
|---|---|---|
| 1.430 | 1.425 | 1.410 |
| 1.430 | 1.420 | 1.410 |
| 1.430 | 1.420 | 1.410 |
| 1.430 | 1.420 | 1.405 |
| 1.430 | 1.420 | 1.405 |
| 1.430 | 1.420 | 1.405 |
| 1.430 | 1.420 | 1.405 |
| 1.430 | 1.420 | 1.405 |
| 1.430 | 1.420 | 1.405 |
| 1.425 | 1.420 | 1.400 |
| 1.425 | 1.420 | 1.400 |
| 1.425 | 1.420 | 1.400 |
| 1.425 | 1.420 | 1.400 |
| 1.425 | 1.415 | 1.400 |
| 1.425 | 1.415 | 1.400 |
| 1.425 | 1.415 | 1.400 |

Data on the Open Circuit Test.

Battery "F"

Taken each day for 48 days.

| Volts | Volts | Volts |
|---|---|---|
| 1.520 | 1.510 | 1.490 |
| 1.520 | 1.510 | 1.485 |
| 1.520 | 1.505 | 1.485 |
| 1.520 | 1.505 | 1.485 |
| 1.520 | 1.505 | 1.485 |
| 1.520 | 1.500 | 1.480 |
| 1.520 | 1.500 | 1.480 |
| 1.515 | 1.500 | 1.480 |
| 1.515 | 1.500 | 1.480 |
| 1.515 | 1.500 | 1.480 |
| 1.515 | 1.500 | 1.480 |
| 1.515 | 1.495 | 1.480 |
| 1.515 | 1.495 | 1.480 |
| 1.515 | 1.495 | 1.480 |
| 1.515 | 1.495 | 1.480 |
| 1.510 | 1.490 | 1.480 |

Data on the Open Circuit Test.

Battery "H"

Taken every twenty four hours.

| Volts | Volts | Volts |
|---|---|---|
| 1.500 | 1.495 | 1.480 |
| 1.500 | 1.495 | 1.480 |
| 1.500 | 1.495 | 1.475 |
| 1.500 | 1.495 | 1.475 |
| 1.500 | 1.490 | 1.470 |
| 1.500 | 1.490 | 1.470 |
| 1.500 | 1.490 | 1.470 |
| 1.500 | 1.490 | 1.470 |
| 1.500 | 1.490 | 1.470 |
| 1.500 | 1.490 | 1.465 |
| 1.500 | 1.490 | 1.465 |
| 1.500 | 1.485 | 1.465 |
| 1.500 | 1.485 | 1.460 |
| 1.500 | 1.485 | 1.460 |
| 1.495 | 1.480 | 1.460 |
| 1.495 | 1.480 | 1.460 |

Data on the Open Circuit Test.

Battery "I"

Taken each day for 48 days.

| Volts | Volts | Volts |
|---|---|---|
| 1.445 | 1.430 | 1.416 |
| 1.445 | 1.430 | 1.410 |
| 1.445 | 1.430 | 1.410 |
| 1.445 | 1.430 | 1.410 |
| 1.445 | 1.430 | 1.405 |
| 1.445 | 1.430 | 1.405 |
| 1.445 | 1.430 | 1.405 |
| 1.445 | 1.430 | 1.400 |
| 1.445 | 1.425 | 1.400 |
| 1.440 | 1.425 | 1.395 |
| 1.440 | 1.425 | 1.390 |
| 1.440 | 1.420 | 1.385 |
| 1.440 | 1.420 | 1.380 |
| 1.435 | 1.420 | 1.375 |
| 1.435 | 1.415 | 1.370 |
| 1.435 | 1.415 | 1.360 |

Data on the Open Circuit Test.

Battery "K"

Taken each day for 48 days.

| Volts | Volts | Volts |
|---|---|---|
| 1.480 | 1.470 | 1.440 |
| 1.480 | 1.470 | 1.435 |
| 1.480 | 1.470 | 1.435 |
| 1.480 | 1.470 | 1.430 |
| 1.480 | 1.470 | 1.430 |
| 1.480 | 1.465 | 1.425 |
| 1.480 | 1.465 | 1.425 |
| 1.480 | 1.460 | 1.420 |
| 1.480 | 1.460 | 1.415 |
| 1.475 | 1.460 | 1.410 |
| 1.475 | 1.455 | 1.410 |
| 1.475 | 1.455 | 1.405 |
| 1.475 | 1.450 | 1.400 |
| 1.475 | 1.445 | 1.400 |
| 1.475 | 1.445 | 1.400 |

Data on the Open Circuit Test.

Battery "L"

Taken each day for 48 days.

| Volts | Volts | Volts |
|---|---|---|
| 1.420 | 1.420 | 1.420 |
| 1.420 | 1.420 | 1.420 |
| 1.420 | 1.420 | 1.420 |
| 1.420 | 1.420 | 1.420 |
| 1.420 | 1.420 | 1.420 |
| 1.420 | 1.420 | 1.420 |
| 1.420 | 1.420 | 1.420 |
| 1.420 | 1.420 | 1.420 |
| 1.420 | 1.420 | 1.420 |
| 1.420 | 1.420 | 1.420 |
| 1.420 | 1.420 | 1.420 |
| 1.420 | 1.420 | 1.420 |
| 1.420 | 1.420 | 1.420 |
| 1.420 | 1.420 | 1.420 |
| 1.420 | 1.420 | 1.420 |
| 1.420 | 1.420 | 1.420 |

Data on the Open Circuit Test.

Battery "M"

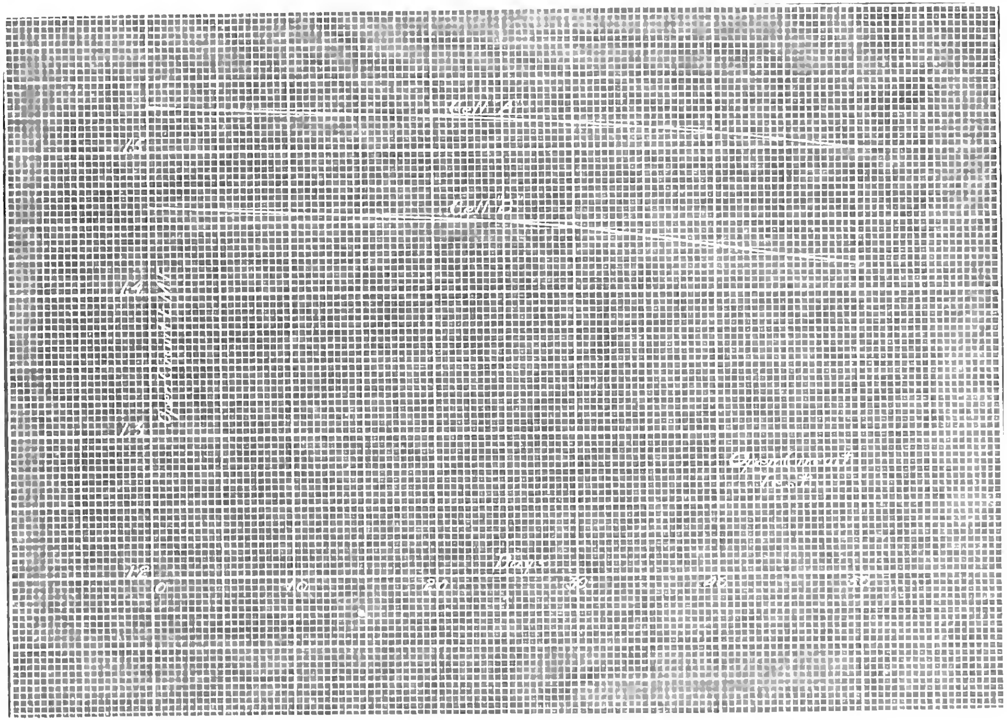
Taken each day for 48 days

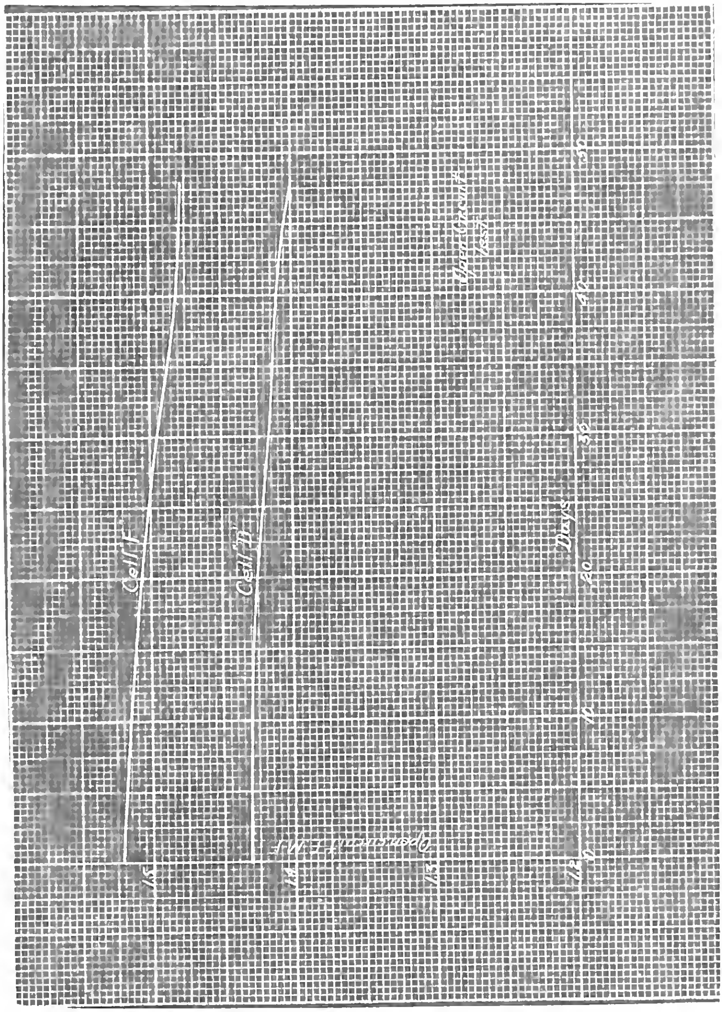
| Volts | Volts | Volts |
|---|---|---|
| 1.450 | 1.440 | 1.420 |
| 1.450 | 1.440 | 1.420 |
| 1.450 | 1.435 | 1.415 |
| 1.450 | 1.435 | 1.415 |
| 1.450 | 1.435 | 1.415 |
| 1.450 | 1.435 | 1.415 |
| 1.450 | 1.435 | 1.410 |
| 1.450 | 1.435 | 1.410 |
| 1.445 | 1.435 | 1.410 |
| 1.445 | 1.430 | 1.400 |
| 1.445 | 1.430 | 1.400 |
| 1.445 | 1.430 | 1.400 |
| 1.445 | 1.430 | 1.400 |
| 1.445 | 1.425 | 1.400 |
| 1.445 | 1.425 | 1.400 |

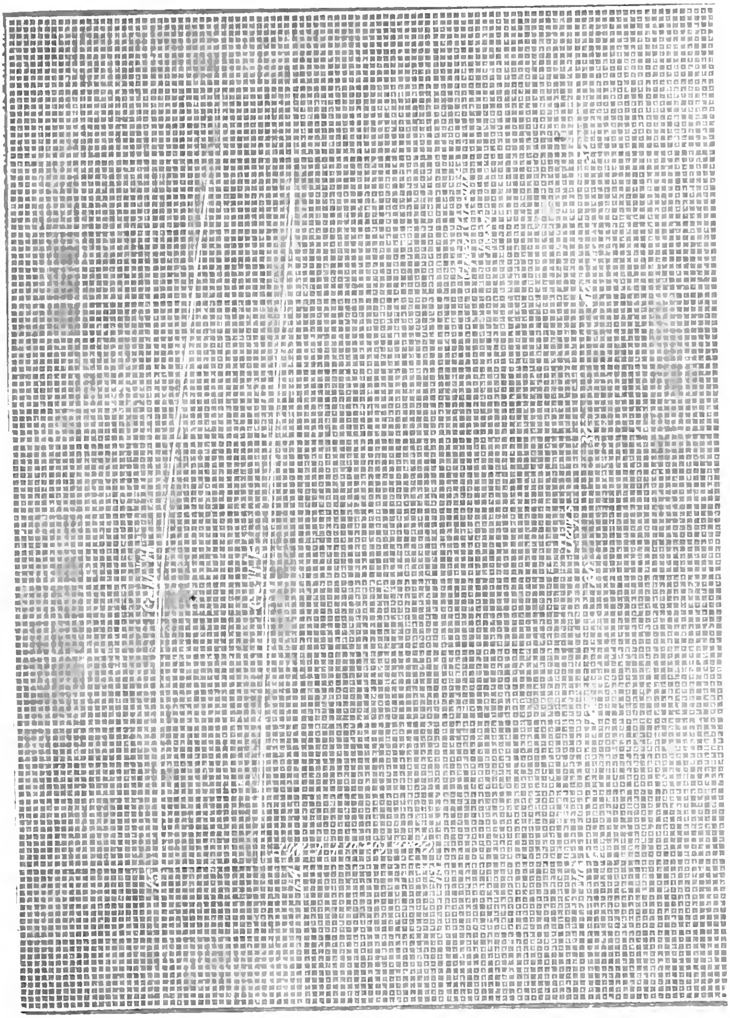
## Curves.

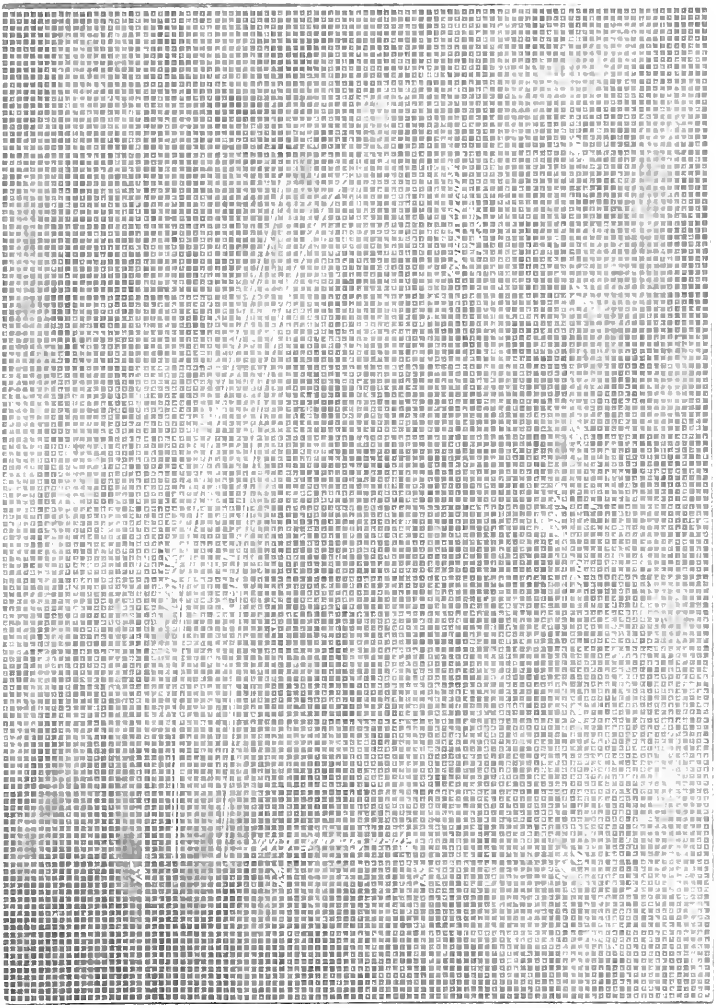
### Open Circuit Test.

The following curves show the relation between the open circuit electromotive force and the length of time, in days, of the cells under test.


Cell "A"
Cell "B"
1.5
1.4
1.3
1.2
0
10
20
30
40
50
Days


Cell "F"
Cell "D"
Open Circuit Test
Open circuit E.M.F.
Days
1.5
1.4
1.3
1.2
0
10
20
30
40
50






Cell M
Days

Part III.

The Temperature Test.

The purpose of this test is to show the behavior of dry cells when submitted to an increasing temperature; to show the effect of temperature upon the internal resistance of the cell.

Figure II.

A sectional view of the apparatus for varying the temperature; and a scheme of the connections for the temperature test.

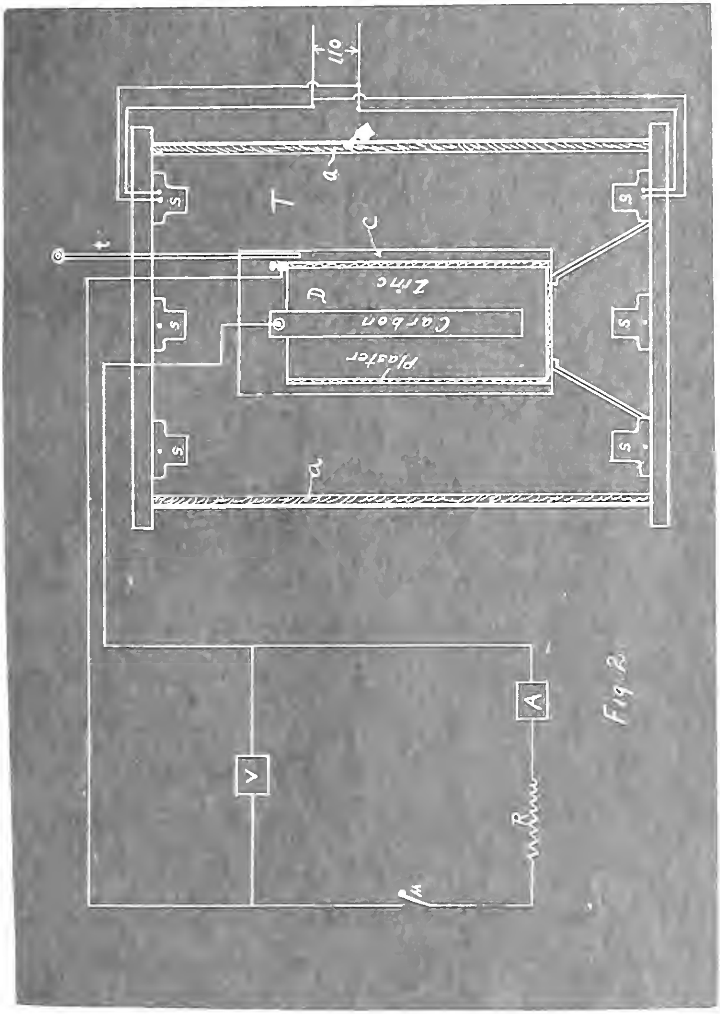



Fig. 2

## The Temperature Test.

Dry cells are very often used in places where the temperature of the surrounding atmosphere is much above normal room temperature. Ordinarily dry cells are used where the temperature is very close to normal room temperature.

This test was carried on by varying the temperature of the cell and taking readings of the open circuit electromotive force, the closed circuit electromotive force, and the current at each variation.

The apparatus was set up according to the scheme shown in Figure 2. T is a galvanized iron tank with heavy wooden top and base. The galvanized iron part of the outer tank was lined with asbestos a. Inside this tank, supported on legs, is a smaller galvanized iron tank C, inside of which is placed the dry cell D to be tested. Close to the outer edge of the top and the base of the tank T is a circle of lamp sockets S, into which are placed incandescent lamps. These lamps are connected to a 110-volt

lighting circuit, and by taking out or putting in lamps the temperature in the chamber C can be regulated. Through a hole in the cover and down into the chamber C is a thermometer for measuring the temperature.

In series with the cell D is connected an ammeter A, a resistance R which is known, and a switch M. Across the cell is connected the voltmeter V. With the switch M open the voltmeter reads the open circuit voltage of the cell, and with switch M closed the voltmeter reads the closed circuit voltage of the cell. Knowing the open and the closed circuit voltage, the value of the resistance R, and the current flowing through the ammeter, the internal resistance of the cell can be calculated by the formula $r = \frac{E_o - E_c}{I} R$. $E_c$ will always be less than $E_o$ due to the drop of electromotive force in the cell when it is discharging an appreciable amount of current.

The first set of readings was taken at about 70F°, room temperature. By means of the lamps the

temperature was varied in increments up to nearly 300°. A set of readings was taken at each variation, and the internal resistance calculated each time. However, before any readings were taken the cell under test was allowed to remain at that temperature until there was no doubt about the temperature being the same throughout all parts of the cell.

At about 225F° the sealing compound of the cells melted, but as it formed a thick layer over the top of the electrolyte, it can be safely assumed that it caused no error in the results.

One of each of the different makes of cells was tested and all the data, together with the curves is recorded on the following pages.

Data on the Temperature Test.

Battery "A"

| Temp. F° | $E_o$ | $E_c$ | I | R |
|---|---|---|---|---|
| 70 | 1.500 | 1.410 | .80.0 | .1995 |
| 197 | 1.500 | 1.430 | .80.0 | .1550 |
| 258 | 1.490 | 1.436 | .80.0 | .1330 |
| 240 | 1.466 | 1.410 | .80.0 | .1220 |

Rise in temperature - - - - - - - - - - - - - -170°

Maximum fall in open circuit voltage - - - .034

Maximum rise in closed circuit voltage - - .026

Maximum fall in current - - - - - - - - - - - 0

Decrease in internal resistance - - - - - - .0775

Data on the Temperature Test.

Battery "B"

| Temp. F° | $E_o$ | $E_c$ | I | R |
|---|---|---|---|---|
| 75 | 1.420 | 1.290 | .720 | .3200 |
| 148 | 1.434 | 1.300 | .725 | .3180 |
| 153 | 1.440 | 1.308 | .725 | .3225 |
| 170 | 1.444 | 1.320 | .730 | .3050 |
| 209 | 1.446 | 1.322 | .730 | .3050 |
| 254 | 1.430 | 1.342 | .750 | .2315 |

Rise in temperature - - - - - - - - - - - - - 179°

Maximum rise in open circuit voltage - - - .026

Maximum rise in closed circuit voltage - - .052

Maximum rise in current - - - - - - - - - - .030

Decrease in internal resistance - - - - - - .091

Data on the Temperature Test.

Battery "D"

| Temp. F° | $E_o$ | $E_c$ | I | R |
|---|---|---|---|---|
| 74 | 1.400 | 1.276 | .700 | .3140 |
| 158 | 1.420 | 1.290 | .720 | .3200 |
| 183 | 1.430 | 1.296 | .720 | .3300 |
| 212 | 1.434 | 1.290 | .710 | .3595 |
| 235 | 1.434 | 1.310 | .705 | .3110 |

Rise in temperature - - - - - - - - - - - - 161°

Maximum rise in open circuit voltage - - - .034

Maximum rise in closed circuit voltage - - .034

Maximum rise in current - - - - - - - - - .020

Maximum rise in internal resistance - - - - .0485

Data on the Temperature Test.

Battery "E"

| Temp. F° | $E_o$ | $E_c$ | I | R |
|---|---|---|---|---|
| 75 | 1.406 | 1.304 | .720 | .2510 |
| 115 | 1.418 | 1.320 | .730 | .2475 |
| 130 | 1.422 | 1.328 | .730 | .2280 |
| 151 | 1.426 | 1.336 | .730 | .2180 |
| 182 | 1.426 | 1.340 | .740 | .2065 |
| 210 | 1.436 | 1.360 | .750 | .1795 |
| 235 | 1.434 | 1.366 | .750 | .1605 |

Rise in Temperature - - - - - - - - - - - - 160°

Maximum rise in open circuit voltage- - - - .030

Maximum rise in closed circuit voltage- - - .062

Maximum rise in current - - - - - - - - - - .030

Decrease in resistance - - - - - - - - - - .0905

Data on the Temperature Test.

Battery "F"

| Temp. F° | $E_o$ | $E_c$ | I | R |
|---|---|---|---|---|
| 68 | 1.480 | 1.394 | .770 | .1975 |
| 105 | 1.480 | 1.396 | .772 | .1925 |
| 146 | 1.482 | 1.402 | .775 | .1830 |
| 191 | 1.482 | 1.416 | .780 | .1498 |
| 209 | 1.434 | 1.346 | .750 | .2020 |
| 235 | 1.434 | 1.360 | .750 | .1750 |

Rise in temperature - - - - - - - - - - - - 167°

Maximum rise in open circuit voltage- - - - .048

Maximum fall in closed circuit voltage- - - .070

Maximum fall in current - - - - - - - - - - .030

Decrease in internal resistance - - - - - - .027

Data on the Temperature Test.

Battery "E"

| Temp. F° | $E_o$ | $E_c$ | I | R |
|---|---|---|---|---|
| 70 | 1.460 | 1.364 | .760 | .2250 |
| 101 | 1.464 | 1.378 | .770 | .1980 |
| 147 | 1.474 | 1.396 | .775 | .1780 |
| 190 | 1.480 | 1.404 | .780 | .1725 |
| 255 | 1.480 | 1.416 | .786 | .1440 |

Rise in temperature - - - - - - - - - - - - 185°

Maximum rise in open circuit voltage- - - - .020

Maximum rise in closed circuit voltage- - - .052

Maximum rise in current - - - - - - - - - - .026

Decrease in internal resistance - - - - - - .080

Data on the Temperature Test.

Battery "I"

| Temp. F° | $E_o$ | $E_c$ | I | R |
|---|---|---|---|---|
| 75 | 1.360 | 1.272 | .700 | .2220 |
| 130 | 1.430 | 1.345 | .712 | .2115 |
| 192 | 1.440 | 1.358 | .720 | .2020 |
| 232 | 1.460 | 1.380 | .731 | .1935 |
| 257 | 1.466 | 1.390 | .738 | .1820 |
| 281 | 1.470 | 1.395 | .740 | .1795 |

Rise in Temperature - - - - - - - - - - - - 206°

Maximum rise in open circuit voltage- - - - .110

Maximum rise in closed circuit voltage- - - .123

Maximum rise in current - - - - - - - - - - .040

Decrease in internal resistance - - - - - - .0435

Data on the Temperature Test.

Battery "K"

| Temp. F° | $E_o$ | $E_c$ | I | R |
|---|---|---|---|---|
| 75 | 1.400 | 1.300 | .710 | .2490 |
| 130 | 1.410 | 1.312 | .720 | .2410 |
| 153 | 1.422 | 1.324 | .728 | .2380 |
| 180 | 1.428 | 1.336 | .737 | .2210 |
| 212 | 1.431 | 1.341 | .750 | .2125 |
| 250 | 1.440 | 1.364 | .759 | .1770 |

Rise in temperature - - - - - - - - - - - - 175°

Maximum rise in open circuit voltage-- - - .040

Maximum rise in closed circuit voltage- - - .064

Maximum rise in current - - - - - - - - - - .049

Decrease in internal resistance - - - - - - .072

Data on the Temperature Test.

Battery "L"

| Temp. F° | $E_o$ | $E_c$ | I | R |
|---|---|---|---|---|
| 74 | 1.420 | 1.330 | .720 | .2210 |
| 124 | 1.430 | 1.341 | .729 | .2160 |
| 143 | 1.438 | 1.350 | .740 | .2110 |
| 180 | 1.452 | 1.365 | .744 | .2070 |
| 221 | 1.460 | 1.380 | .748 | .1895 |
| 270 | 1.472 | 1.400 | .752 | .1695 |

Rise in Temperature - - - - - - - - - - - - 196°

Maximum rise in open circuit voltage- - - - .052

Maximum rise in closed circuit voltage- - - .070

Maximum rise in current - - - - - - - - - - .032

Decrease in internal resistance - - - - - - .0515

Data on the Temperature Test.

Battery "M"

| Temp. F° | $E_o$ | $E_c$ | I | R |
|---|---|---|---|---|
| 70 | 1.400 | 1.320 | .700 | .2080 |
| 127 | 1.407 | 1.327 | .710 | 1995 |
| 147 | 1.420 | 1.340 | .717 | .1975 |
| 183 | 1.430 | 1.354 | .721 | .1840 |
| 219 | 1.450 | 1.374 | .742 | .1985 |
| 267 | 1.452 | 1.378 | .750 | .2050 |

Rise in temperature - - - - - - - - - - - - - 197°

Maximum rise in open circuit voltage- - - - .052

Maximum rise in closed circuit voltage- - - .058

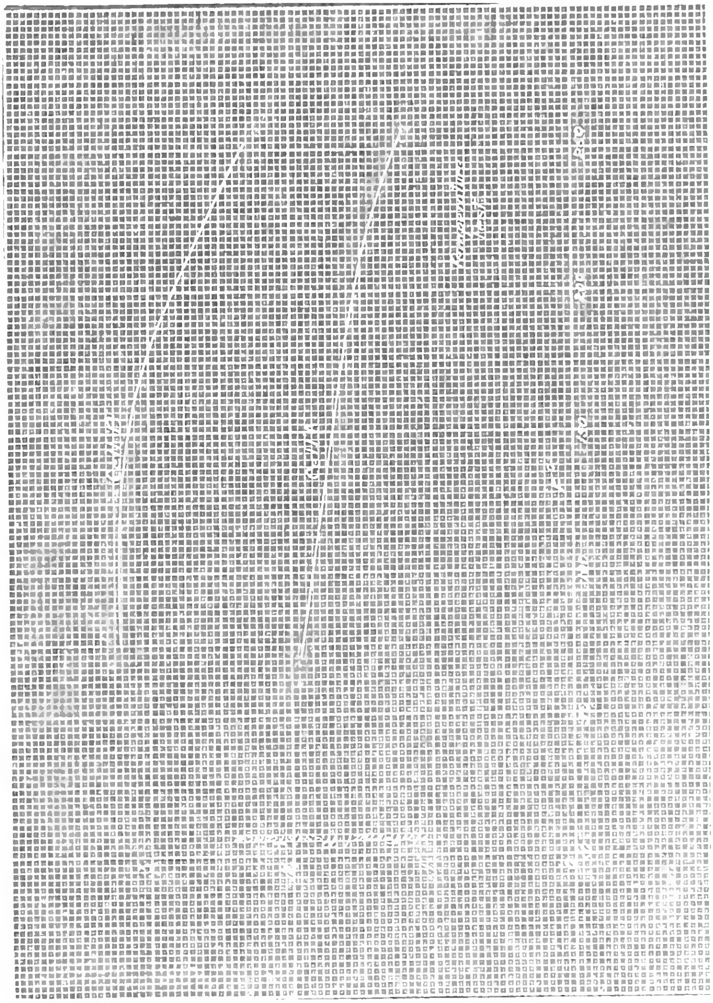
Maximum rise in current - - - - - - - - - - .050

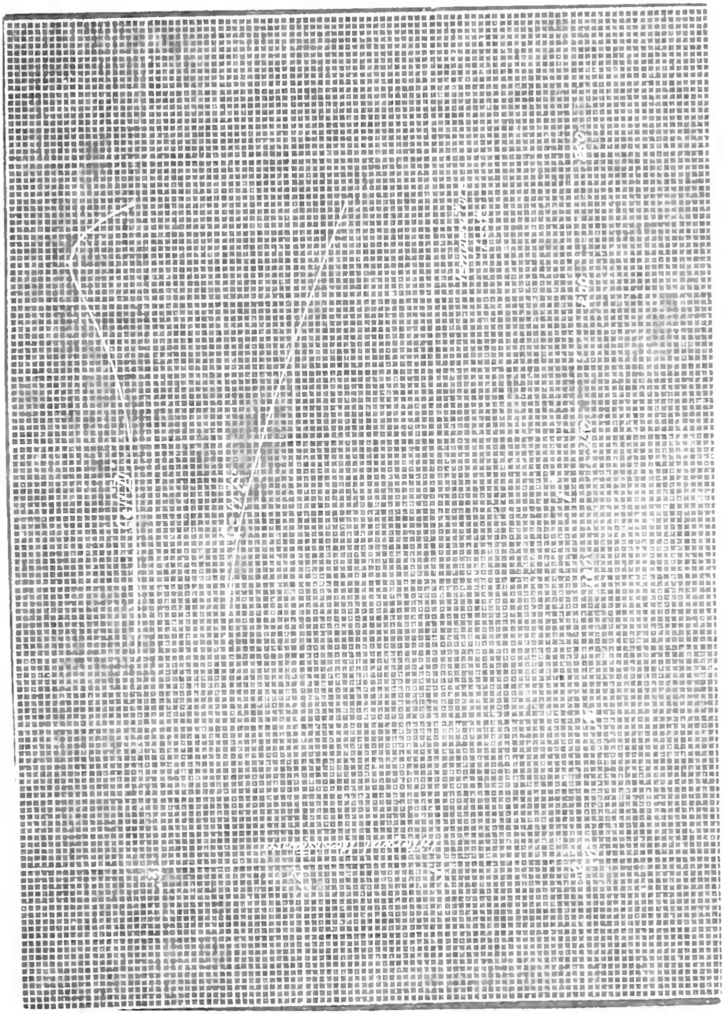
Decrease in internal resistance - - - - - - .019

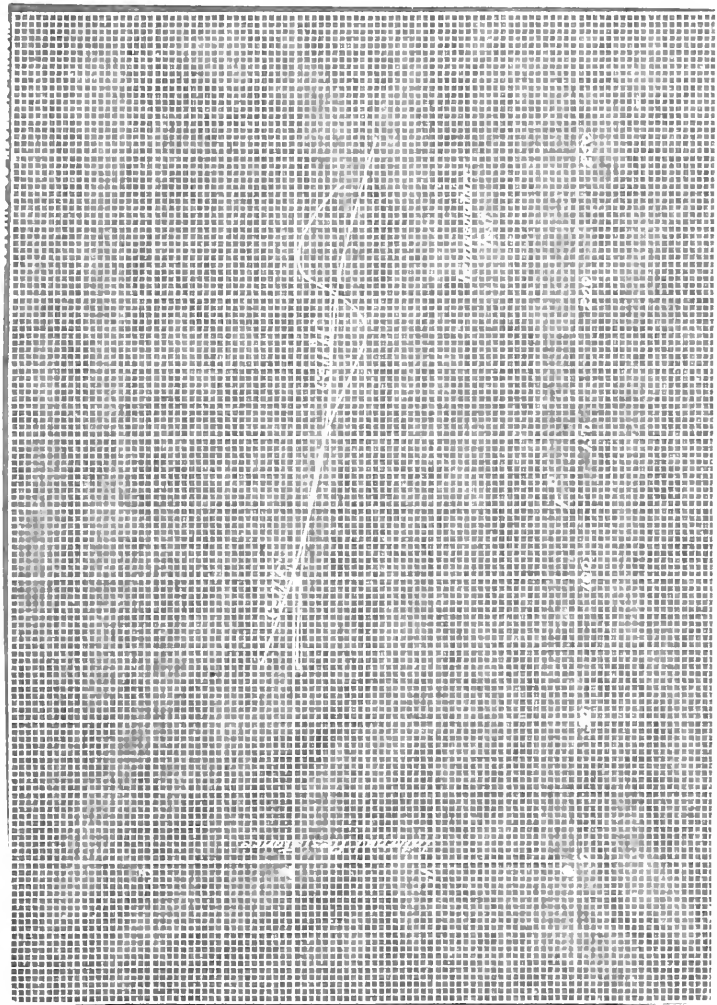
## Curves.

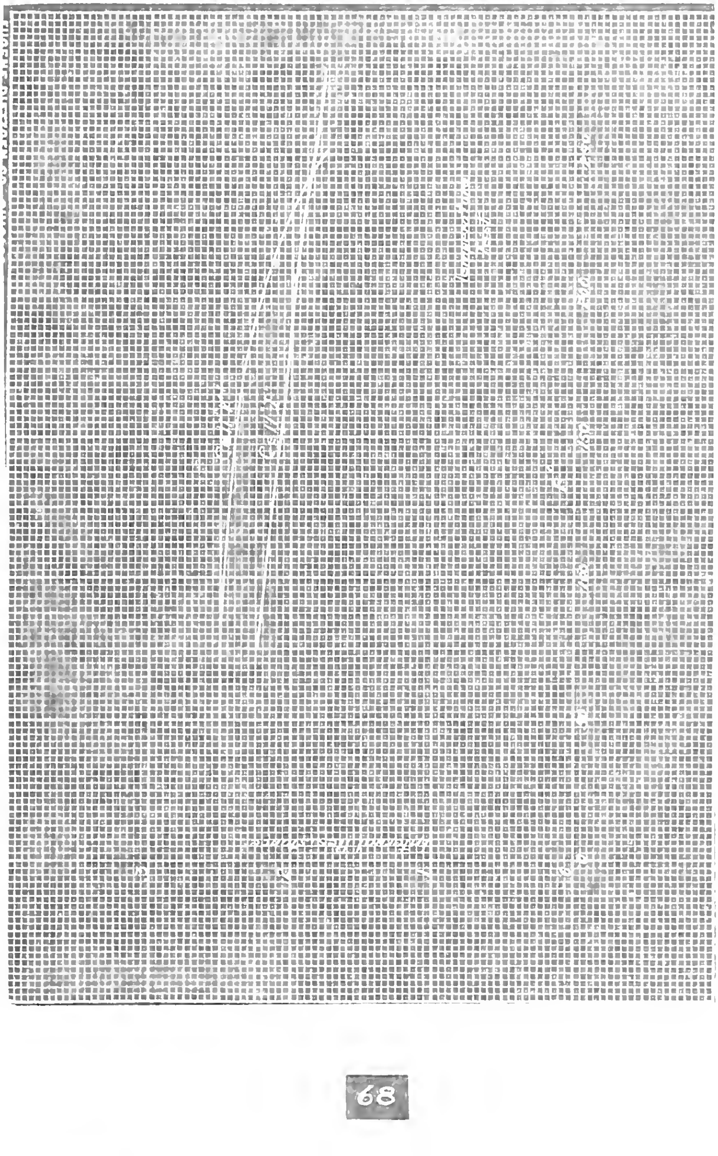
### The Temperature Test.

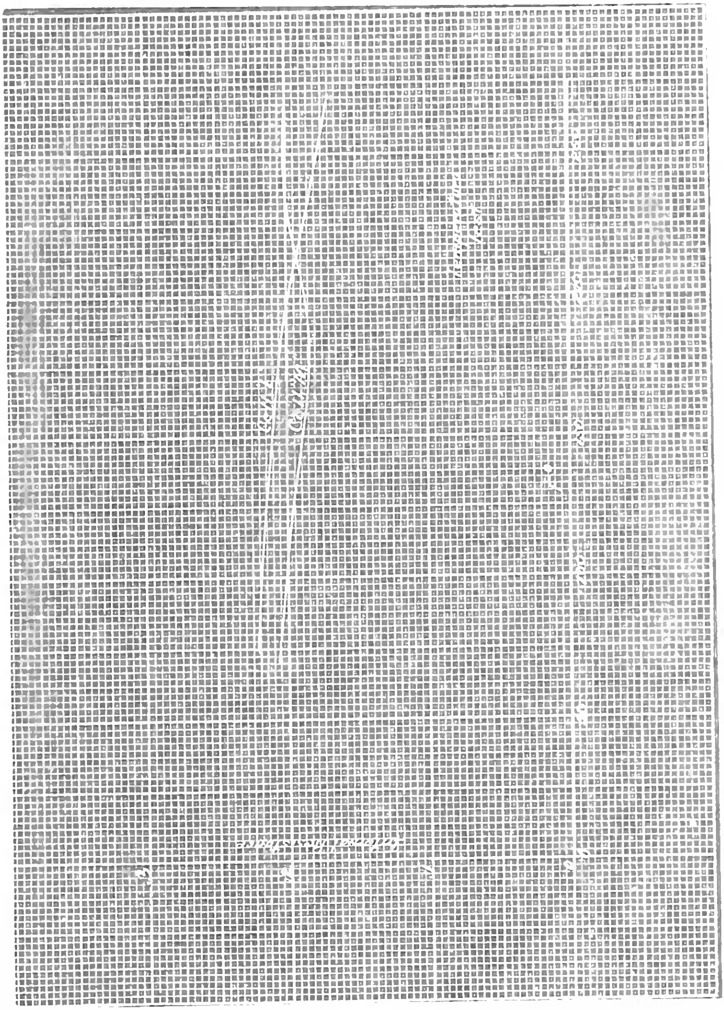
Curves showing the relation between the internal resistance of the cells and the temperature at which the resistances were taken. The curves are self evident and need no explanation.











## Part IV.

### The Recuperative Test.

The purpose of this test is to show how much and with what rapidity a dry cell will regain its power when left standing idle after it has been short circuited through a resistance.

## The Recuperative Test.

The recuperative test consisted merely of connecting the cell to be tested in series with a resistance and an ammeter and allowing the cell to remain under these conditions for a length of time. The cells were connected in series with an ammeter and a resistance and allowed to stand with the circuit closed for a little over three hours.

After the closed circuit voltage had dropped somewhat below one volt the circuit was opened and readings of the open circuit voltage taken every twenty minutes until 2 hours and 40 minutes of time had elapsed.

The voltage of cell "A" increased form 1 to 1.17 volts; "B" from .92 to 1.11 volts; "C" from 0 to .98 volts; "D" from .87 to 1.06 volts; "E" from 1.02 to 1.182 volts; "F" from .98 to 1.14 volts; "H" from .98 to 1.182 volts; "I" from .85 to 1.02 volts; "K" from 1.03 to 1.21 volts; "L" from .85 to 1.042 volts; and "M" from 1.0 to 1.17 volts.

Cell "C" dropped to zero voltage after it had been in the circuit for less than 2 hours; but it recuperated from 0 to .98 volts, showing that for other than short intermittent uses it is of no practical value, and if it were not for its quick recovery it would be absolutely useless. The cell was omitted in the other tests for the reason of its low, short circuited life. The other cells gave all about the same results and it can be safely assumed that these results are an average value for all makes of dry cells.

## Part V.

Five plates showing a cross-sectional view of the cells under test.

Cell "A" was drawn with the sections cross-sectioned in order to give the reader an idea of the arrangement of the parts of a dry cell. The outline and dimensions of the other cells are given and by referring to cell "A" the various dimensions are explained.

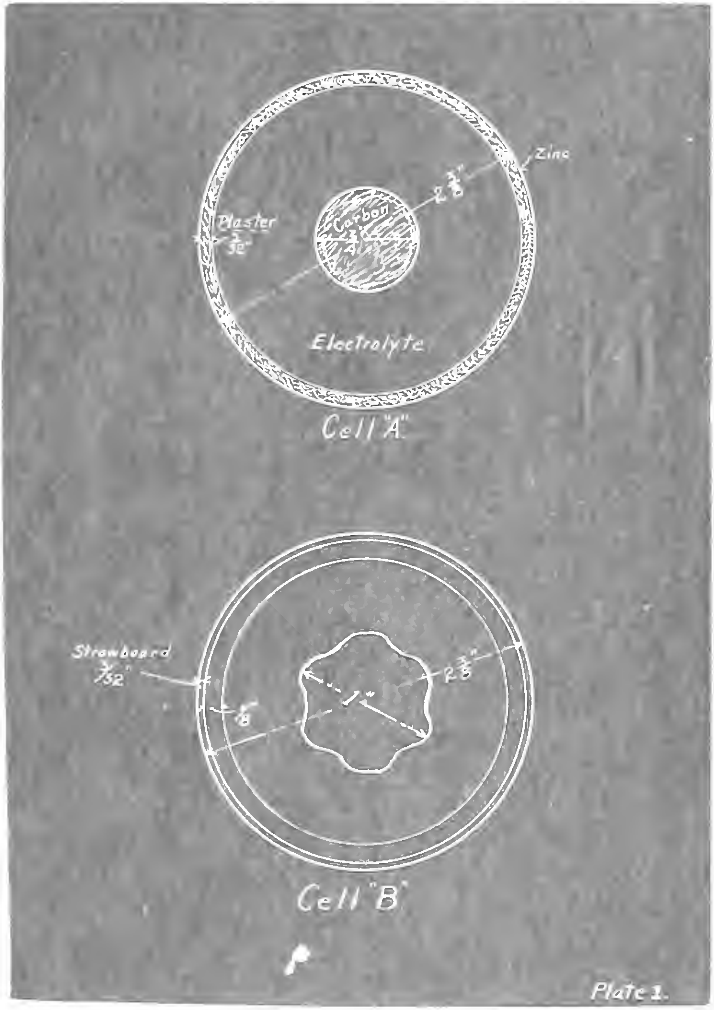
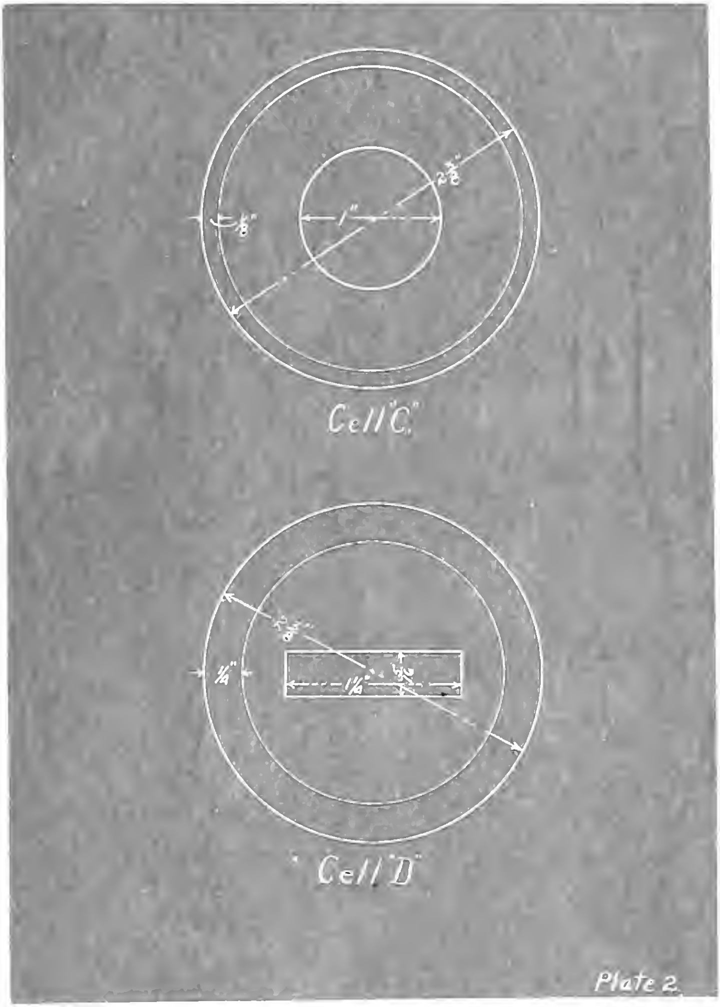
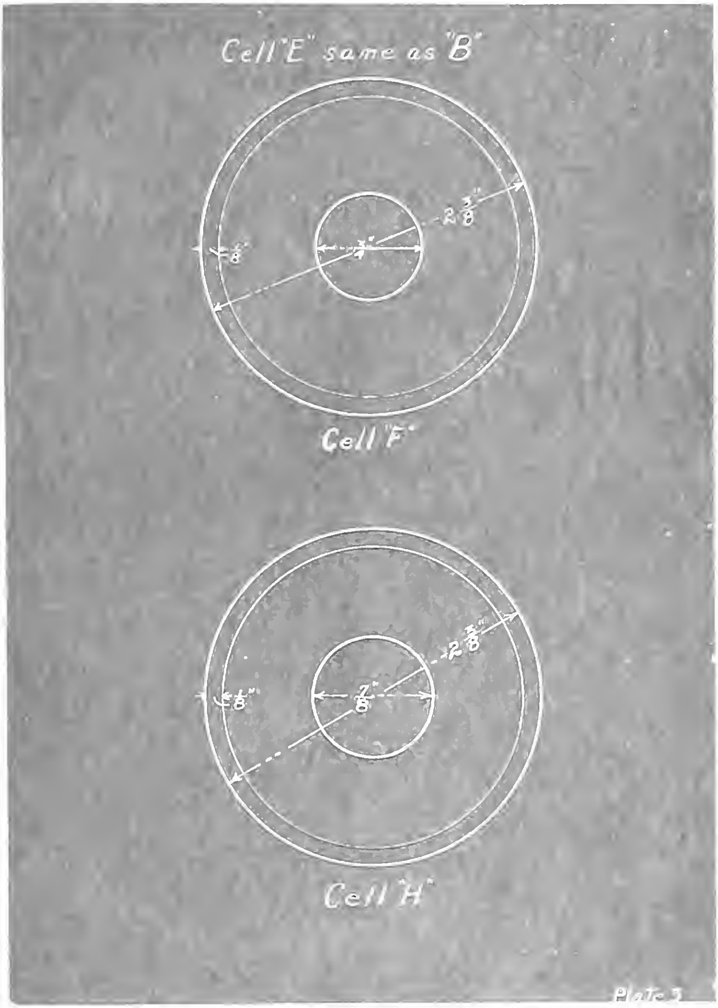
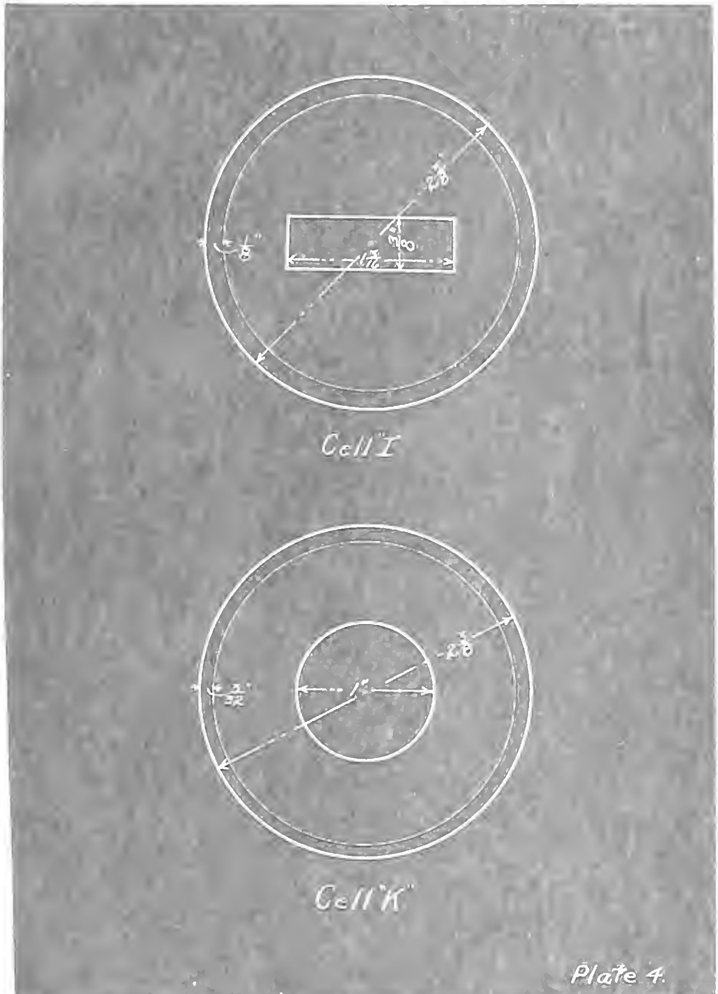

Zinc
Plaster
Carbon
Electrolyte
Cell "A"
Strawboard
3/32"
1"
Cell "B"

Plate 1.


1"
Cell "C"
Cell "D"
Plate 2.


Cell "E" same as "B"
Cell "F"
Cell "H"



Cell "I"

Cell "K"

Plate 4.

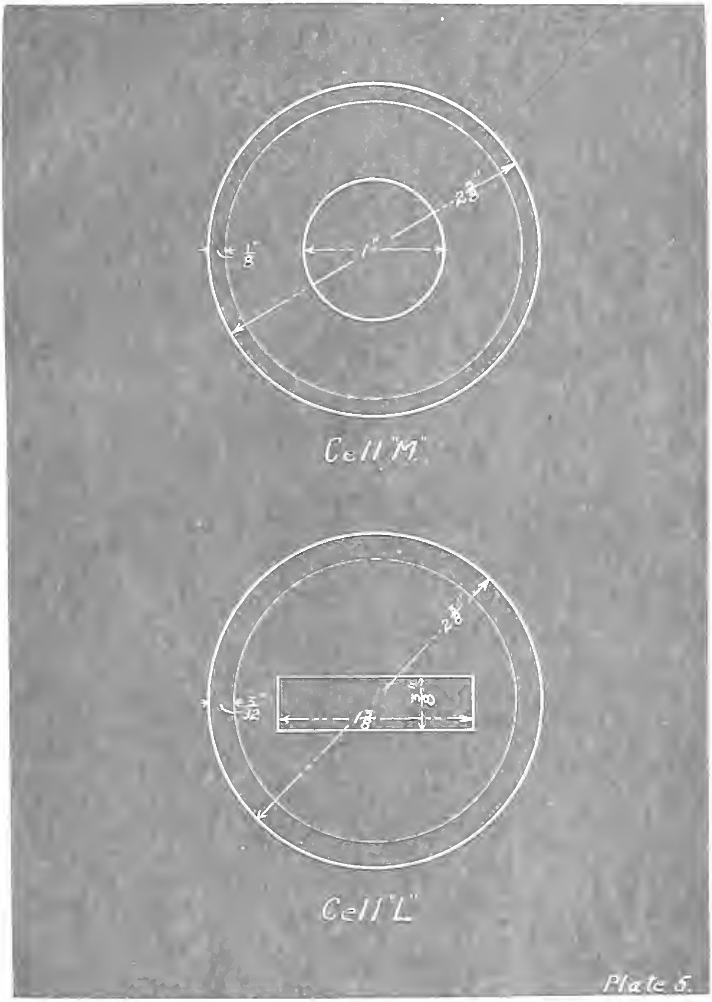



Plate 5.

# Part VI.

## A Short Summary of the Tests.

## Summary.

A thoroughly practical set of tests on dry cells having been explained in detail it may be well now to give a summary of the most important points brought out. Although only 10 makes of cells were tested, (only 10 makes were tested since the 11th was found to be too short lived to give any good practical results) it can be said that these are a fair representation of all the makes of dry cells on the market today.

In making a summary of the data it may be well to tabulate the data of the three tests as follows, and by reading the tables one can tell at a glance the performance of each of the makes of cells.

The Intermittent Test.

| Make of cell. | Internal res. | Watt-hours del. | Watt-hours / cu in. |
|---|---|---|---|
| A | .243 | 58.45 | 2.63 |
| B | .307 | 53.33 | 2.55 |
| D | .293 | 52.94 | 2.40 |
| E | .189 | 56.97 | 2.72 |
| F | .166 | 57.54 | 2.74 |
| H | .274 | 50.17 | 2.46 |
| I | .248 | 53.15 | 2.61 |
| K | .238 | 56.45 | 2.32 |
| L | .430 | 46.68 | 2.18 |
| M | .160 | 50.80 | 2.54 |

The Open Circuit Test.

| Make of cell | Volts at beginning | Volts after 48 days |
|---|---|---|
| A | 1.530 | 1.500 |
| B | 1.460 | 1.420 |
| D | 1.430 | 1.400 |
| E | 1.430 | 1.400 |
| F | 1.520 | 1.480 |
| H | 1.500 | 1.460 |
| I | 1.445 | 1.360 |
| K | 1.480 | 1.400 |
| L | 1.420 | 1.420 |
| M | 1.450 | 1.400 |

The Recuperative Test.

| Make of cell | Open circuit e.m.f. after 3.16 hours output | Open circuit e.m.f. after 2.16 hours recovery. |
|---|---|---|
| A | 1.00 | 1.170 |
| B | .92 | 1.110 |
| C | 0 | .980 |
| D | .87 | 1.060 |
| E | 1.02 | 1.182 |
| F | .98 | 1.140 |
| H | .98 | 1.182 |
| I | .85 | 1.020 |
| K | 1.03 | 1.210 |
| L | .85 | 1.042 |
| M | 1.00 | 1.170 |

-*FINIS*-